

The End of Traffic and the

Future of Access

A Roadmap to the New
Transport Landscape



David M. Levinson



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AND THE
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NEW TRANSPORT
LANDSCAPE

NETWORK DESIGN LAB

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First printing, October 2017

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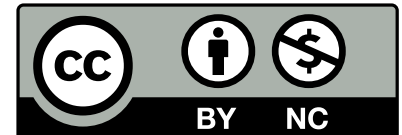
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Acknowledgments and Dedications

Thanks much to the army of recruited volunteers who had the courtesy to review and comment on initial drafts (listed alphabetically): Kay Axhausen, Robert Cervero, Tony Dutzik, Ahmed El-Geneidy, Yingling Fan, Eric Jaffe, David King, Arnoud Lagendijk, Scott Le Vine, Wes Marshall, Adam Millard-Ball, Andrew Owen, Robert Poole, Daniel Rodriguez, Lisa Schweitzer, and Jarrett Walker.

Elements of the book have appeared in much rawer form on our blogs: [The Transportist](#), [Vehicle for a Small Planet](#), as well as [streets.mn](#). The authors thank Eric Jaffe, Reihan Salam, Angie Schmitt, Walter Russell Meade for picking up on and discussing some of the earlier blog posts that formed source material for the book and James Pethokoukis, Horace Dediu and Jim Zellmer, and Charles Marohn for useful podcast interviews.

Parts of Chapter 5 are adapted from “Electric Avenue” in *Foreign Affairs* (May/June 2014). Parts of other chapters are adapted from “Climbing Mount Next.”¹

Some of this research has been supported by the Minnesota Department of Transportation, the Local Road Research Board, and the Metropolitan Council of the Twin Cities. The authors are solely responsible for the content.

Parts of the book appear in *The Transportation Futures Project: Planning for Technology Change*.²

The first two editions of this book were published as *The End of Traffic and the Future of Transport*.

For David M. Levinson



Figure 2: To William Louis Garrison (1924-2015)

For Kevin J. Krizek

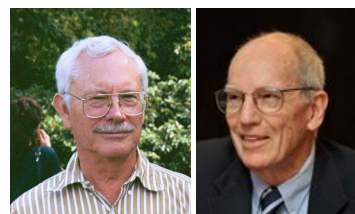


Figure 3: To Richard L. Morrill (b. 1934) and David R. Godschalk (b. 1931)

¹ (Levinson 2015).

² (Levinson et al. 2016).

Preface: Transport is Interesting, Again

Less than two decades into the new millennium, transport is becoming interesting (again?). Such resurgence is why we initiated this book in 2015. Revolutionary technical advances are taking root; evolutionary social forces are responding; together, these phenomena are changing how people access and exchange goods. Transport and planning discussions are now being reshaped, prompting even seasoned transport professionals to appear as neophytes. Our aim with this work is straightforward: to reframe the evolving nature of debates about transport and to shape perspectives about the future of transport in cities.

Each person's perspective is shaped by their own experiences. Both of us have sat in Minnesota car dealerships on gray and snowy April days while our so-called 'tickets to freedom' received their 15,000 mile³ checkup. In these times, we have each contemplated the volume of salt that the car was exposed to over the past year and incremental quantities of rust our car accrued. We are not alone in these experiences. They are familiar for those who have lived north of the US's Mason-Dixon line. In such gloomy environs, one feels little joy associated with auto-mobility. One surprising reflection on all of this is that little has changed in these respects (or significantly improved) for as long as most people can remember.

³ 25,000 km

The 1950s created the institutions and the financing tools needed to greatly expand transport infrastructure. After the onset of the US Interstate Highway System, the 1970s version of the Clean Air Act aimed to address the environmental costs of cars, and subsequent policies have had noticeable success in improving air quality. Public transport, mired in 'crisis' since the 1950s, received a large infusion of federal capital. Not surprisingly, transport planners in the 1980s were vexed with suburban 'gridlock.' They spent time chasing inexpensive strategies based on transport system and travel demand management as the roll-out of the highway network slowed.

Planning buzzwords in the 1990s focused on growth management and concurrency (between development of land and the provision of infrastructure), so that public facilities were ‘adequate.’

Proclaimed as the largest public works project in the world since the Pyramids, there are good reasons the Interstate Highway Act left many legacies. An oft unrealized impact, however, is that for the next half-century, transport centered on the themes of deployment (rolling out the highway network), and management (better operating the system). Transport planning in the Interstate Era focused on more roads here, removing bottlenecks there, better managing capacity over yonder. Innovation, technological or policy, took a back seat. So did doing anything exciting in transport.

The 1992 Highway Bill, more formally the Intermodal Surface Transportation Efficiency Act,⁴ mildly deflected the highway centric trajectory of US transport investments. Reducing the negative externalities attributed to auto use received increased attention; other modes received a boost of funding and acknowledgement. The reaction against auto-mobility gained steam with the warning whistle of rising greenhouse gas emissions and the observations of climate change. In some cities, initiatives might center less around reducing car use and more around enhancing other transport options. Either way, less changed than one would have expected given the revolution in information technologies over the same period.

But now, starting in the 2010s, growing on seeds laid earlier, rapidly transforming transport systems in communities of all sizes are experiencing creative innovation. Globally, cities are witnessing new forms of information and communication technologies coupled with new real-time data enabling new approaches to share resources. These changes are invoking fresh flows of goods and information and allow people to achieve activities in ways unavailable just a few years ago. Borrowing from Thomas Kuhn’s popular 1962 book *The Structure of Scientific Revolutions*, discussions ring of a paradigm shift.⁵ Transport practitioners are encountering anomalous new behaviors that the historically accepted paradigms have difficulty explaining.

What is certain in the future is that humans will maintain desires. Whether for stuff, skills, smarts, esteem, solace, security, salvation, spirituality, space, scenery, love, or socializing, these desires and the way they are accessed change with the times. Most desires have historically been satisfied by moving stuff while traversing distances across physical geographies. People transport themselves to collect some things; they expect other things to come to them. Moving

⁴ The Intermodal Surface Transportation Efficiency Act is refreshingly abbreviated ISTEA (and pronounced Iced Tea).

⁵ (Kuhn 1962).

forward, there is heightened uncertainty about how they will seek to access (or possess) things they care about it. What is paramount for the transport business is to uncover ways to ease how these desires are achieved in ways that comport with goals for which cities claim to be aspiring (e.g., livability, environmental preservation, social cohesion).

In this book we first explore the welcome notion that traffic – as most people have come to know it – is ending and why. We depict a transport context in most communities where new opportunities are prompted by the collision of slow, medium, and fast moving technologies. Fast moving technologies include computers and communication technologies, especially adopted by younger travelers. With an average life span of 11 years, cars would represent medium-moving technologies. The topology of the road network itself is the slowest moving of all, having been in place for years and unlikely to change much in the future. We juxtapose other changes likely to have a near-term impact, including a range of emerging technologies, such as autonomous vehicles, electric vehicles, transit improvements, and better networking of car and cab sharing, referred to as mobility-as-a-service (MaaS).

We develop a framework to conceptualize transport and accessibility more broadly. In this framework, transport systems are being augmented with a range of information technologies.

More specifically, the first part paints a picture about the End of Traffic: data, history, and trends. We focus on what has actually happened (Chapter 1), why what is happening is a good thing (C. 2), the underlying causes (C. 3), how the inevitable conflicts between the timeframes of change keep transportation practice lagging far behind imagined transportation potential (C. 4).

The second part examines upcoming processes that are shaping the future of transport, and their consequences: Electrification (C. 5), Autonomy (C. 6), Connectivity (C. 7), Mobility-as-a-Service (C. 8), Demassification (C. 9), Dematerialization (C. 10), Delivery (C. 11). While these changes are still mostly too small have been measured in the system statistics. We have begun to see the tip of the iceberg in their transformative potential. We look at how even the laggard transit modes will be affected (C. 12). Then, we consider changes to land use (C. 13).

In the third part, the book builds to prescribe planning, finance, and design strategies for communities themselves and more specifically, those responsible for shaping the provision and use of infrastructure in such communities to embrace that better reflect changes. We prescribe new design aspects and priorities for

rights-of-way consistent with the end of traffic (C. 14). We recommend pricing strategies to accelerate the end of traffic (C. 15). These might happen, but they cannot happen without active public direction (unlike the technology changes of dematerialization, electrification, automation, sharing, and cloud commuting, which are on trajectories if not entirely independent of public policy interventions, mostly so). Our last chapter (C. 16) charts paths forward for how transport will redeem itself.

There are things that might happen on their own (with a minimal amount of public policy interference). There are things the public can make happen through directed policies. There are things the public can prevent from happening with policy. We think the culmination of results presents an optimistic perspective, though some have referred to the ideas stated herein as “refreshingly unromantic.” This scenario has causes and effects, and can be compared with a status quo scenario (where traffic neither rises nor falls much) and one where traffic resumes its once seemingly remorseless march upward. We then offer priorities to accelerate these trends. Why delay positive outcomes like the end of traffic congestion, the end of tailpipe emissions, the end of car crashes, and the end of having to pay attention while driving?

This work is far from the first book on the future of transport issues, and we hope not the last. A similar work appeared almost two decades ago by the person to whom this work is dedicated (Bill Garrison); he offered observations back then which remain on-point today, if slow to take root. The content herein derives from our personal observations of and reflections on transport practice and scholarship. The text grew largely out of David’s Transportist blog⁶ which he has been writing since 2006; far fewer ideas may have sprouted in Kevin’s blog, Vehicle for a Small Planet.⁷

Our purview admittedly has three limitations. First, most references and supporting data are United States focused. International readers may appreciate the changing dynamics, but will need to apply the concepts appropriately (easier done in Canada, Australia, New Zealand, and in many parts of Europe). Many of the trends are unfolding globally, albeit at different rates. Second, the phenomena that we describe mostly apply to urban transport systems from the developed world (sometimes referred to as the West or the Global North, though it encompasses very east and south places like Australia and New Zealand). Third, our assessment and projections for several phenomena risk being a bit cavalier in the interests of brevity and readability. This is not a journal article. We would like it to be read. Some conjectures might

⁶ <http://transportist.org>.

⁷ <http://vehicleforasmallplanet.com>.

be unsettling for a few people. We mitigate such 'brushing off' by documenting assumptions and relevant citations in the margins.

This third edition has some enhancements while still following the format of the first two. We grew tired of coming up with excuses for why we could not deliver copies to our parents or to offer you a physical, signed copy. So we are pleased to partner with the Network Design Lab and now offer a physical print edition; the first two editions were released in e-versions only. We inserted revisions throughout reflecting updates to data charts and further graphics that support many of our arguments. And, we changed the order of some text and combed other parts to ensure greater readability and streamlining of ideas. Reviews of past editions of this work appreciated the lively and personal nature of the writing. We retained this feature.

Even if transport is not your bailiwick, there is something interesting for you here. We aim for a quick read – and to encourage you to think outside your immediate realm. By the end of this book (this evening, if you so choose) you will appreciate the changing times in which you live. You will, we hope, appreciate what is new about transport discussions and how definitions of accessibility are being reframed. You will be provided with new ways to think about transport that syncs with a radically changing landscape. Even if transport is not your bailiwick, we think there is something interesting for you here because we conjecture about the places where at least two-thirds of the global population will live by 2050 and how they will satisfy their daily needs. We hope you enjoy reading our prospects.

What Happened to Traffic



Figure 4: What happened to traffic? Photo by Kevin J. Krizek.

DATELINE: JUNE 29, 2056

Today marks the 100th Anniversary of the Interstate Highway Act in the United States. Let's reflect on how travel has changed over the past century.

REMEMBER TRAFFIC? It was only 40 years ago that residents across the globe complained about getting stuck in traffic. Normal 'around town' errands were ensnared in snarled interchanges. Remember when it sometimes took three times longer to cross town than it 'should have'?

But even back then – and largely unnoticed by the naked eye – new transport patterns were taking root. The significance of these patterns, however, failed to be realized. Car traffic leveled off in the

beginning of the century and has fallen fairly steadily ever since. A few keen observers picked this up, but many transport agencies were in denial at the time. Back then, analysts offered two possible futures:

- The first forecast that per capita vehicle travel would pick up on its upward path based on the previous century – a forecast reminiscent of the proverbial ostrich with its sand-encased head.
- A second forecast acknowledged that per capita vehicle travel remained flat, but one where overall traffic grew with population increases. Major transport providers asserted the need for new and wider roads, despite falling traffic overall. More capacity demanded new resources, requiring additional revenues. Many claimed that though private vehicle use was falling across the developed world, on average, it wasn't falling in *their* jurisdiction. And, there were still unsolved problems that don't go away just because travel isn't increasing.

Most public officials failed to anticipate what actually happened. This third future was one where per capita vehicle travel fell significantly. Even acknowledging the initial dip in travel (at least in the US), most observers attributed it to gas prices and the Little Depression of the second Bush Presidency. What went largely unrealized was that travel began dropping before the economy tanked.

REMEMBER WORK? Our great-grandparents (of the World War II era) went to their job six days a week, only taking off for the Sabbath, from the time when they were teenagers. And, their parents worked from childhood, which had yet to be invented. The workforce generally got a full two-day weekend in the middle of the twentieth century. Around the turn of the century, many companies started granting every-other Friday off (the 5/4 schedule). The 3-day weekend was celebrated every other week as the norm. About a decade ago, workers moved to a 9 hour day, 4 days per week at the office, and the other 4 hours were 'at home' work. The rise of the Internet dissolved the once strict separation of home and work. The half of the population that worked in offices could no longer leave work at the office. So they brought their personal lives into the workplace, living what sociologists call the 'blended life.' By 2025 taking every-other Monday off (the 4/3 schedule) was established for office-workers at most large firms. Today, half-days on Wednesdays are common for many office workers, with only Tuesdays, Wednesday, and Thursdays as interactive collaboration

days. In today's 'flipped' office, people file 'paperwork' at home on their own computers, and only show up for collaborative work and meetings.

REMEMBER OFFICE BUILDINGS? Once the heart of cities, we soon discovered high-rise office towers were overbuilt after real-time telecommunication became ubiquitous. Office buildings were reconfigured to be mostly meeting space, with some interim work spaces that became more like cafes or pubs than the cubicles satirized in the 20th century comic strip *Dilbert* and the turn-of-the century movie *Office Space*. After the commercial real estate bubble popped in the famous Skyscraper Crash, many office buildings were torn down or adapted into living space, others remain vacant. With the daily office grind being a phenomenon of the past, work trips cratered.

REMEMBER THE 'AMERICAN DREAM' OF A HOUSE IN THE SUBURBS? Some downtowns were virtually abandoned by business after the Skyscraper Crash. This helped undercut new residential construction in the suburbs, and suburban land prices fell, attracting lower income immigrants, who subdivided large tract mansions into housing for large extended families, and leading to a measurable 'white-flight' back to the center city, as former suburbanites colonized vacant and reconfigured office buildings. While the suburbs were now less expensive, some actually gained population. Lower income residents still own cars, but not as many. The traditional 2- and 3-car garage is being transformed into a workshop, living space, or small store. More urban living, much of it in abandoned and remodeled office buildings, reduced the distances people needed to travel. Many 20-somethings live in these windowless, but well-connected, skyscraper dorms, while artists have begun to occupy and see inspiration in the detritus of the late 20th century skyway network. Cities began to encourage accessory housing, and conversion of garages to apartments.

REMEMBER THE LONG-TERM CAREER? On average, our parents and grand-parents stayed in the same industry (if not the same firm) from high school or college until age 65 or so. Now in 2056, half the population doesn't enter the regular workforce until age 30. The other half leaves well before age 60. They work three different 'full-time' jobs over the course of a career. Individual firms used to cultivate employees, paying for training. Now a 10-year series of unpaid (or low-wage) internships while simultaneously attending

school online or part-time and engaging other pursuits is the norm. Many just receive the Universal Basic Income and have dropped out of the conventional workforce altogether. Over time, the workforce has continued its drop as technology-enabled productivity reduced the value of older workers. With fewer people working, there were fewer work trips.

REMEMBER SHOPPING? Physically traveling to a store used to be the norm for everything. Then came catalogs. Catalogs morphed on the Internet (remember the Amazon.com boom?). Acquiring things now is now clearly a combination of the occasional physical trip to the store (likely for nostalgia-sake or simply entertainment), letting 'bots and virtual agents do the work for you especially for regular stocks like paper towels, napkins, and Spam. And so now most goods get delivered. Going shopping continues its long 50 year drop, and consumption of material goods has declined with it.

REMEMBER ADVERTISING? Internet Adblockers, video-on-demand, and other time-shifting technologies diminished advertising in people's lives. Ads did not disappear, and many companies now want to coat road surfaces with new digital ad-delivery technology. Cash-strapped road agencies are looking favorably on sponsored roads. With less window shopping and a decline in advertising, the culture became less materialistic.

REMEMBER LONG-DISTANCE TRUCKING? Decentralized manufacturing, including 3-D on-demand printing, has begun to replace long-distance shipping of many goods, which can now be made locally. Teamsters used to steer the truck, which are now controlled remotely. Trucking as a profession has seen a long decline.

REMEMBER OWNING A CAR? Nearly a century ago, owning a Pontiac Firebird (or better yet, a Corvette) meant having 'made it,' at least in the US. By 40 years ago it was possible for most city-dwellers to sell their cars and not replace them. By 30 years ago, it became common-place. The taxi – the ultimate in shared vehicles – was transformed from a niche mode to the mainstream. Instead of having a high cost of owning a car but a very low cost per trip, now there is a higher cost per trip, making people think twice, and use cars less. With fewer trips by car, traffic dropped even more.

REMEMBER THE SUV? The Sport Utility Vehicle and pickup truck were used for daily transportation by nearly half the population, though few of them transported much in the way of goods. With vehicles on-demand, when people use cars, they ride in single-passenger cars, saving money and space.

REMEMBER DRIVING IN DOWNTOWN? Cities began to outright ban cars within core areas. Since most residents did not own cars, this became an easy political sell. In those cities, walking, bike, scooter, and bus use soared. This affected not only residents, but anyone going to the city. Cars remain popular for trips outside of cities, but there are fewer cars, fewer car trips per resident, and relatively fewer non-city residents.

REMEMBER TRAFFIC LIGHTS? Without traffic lights, we never would have managed to obtain urban auto-mobility. It was critical scaffolding for the twentieth century auto-dominated city. Today they are preserved in selected districts only for their historic authenticity, not as actual control devices. Traffic is now controlled by signals conducted invisibly through radio spectrum, rather than with colored lights designed for the human driver's eyes, while discrete in-ground sensors detect and guide pedestrians across busy intersections. Today's downtowns are largely car-free zones, so these new controllers are just at the edge of the urban core.

REMEMBER GAS STATIONS? We used to pour liquid petroleum into the tanks of our cars, and burn gasoline for energy, creating smog and greenhouse gases as unwanted byproducts. Today all new cars and trucks are electric, and the gas guzzlers have largely been removed from the road. It will take decades for the environment and climate to recover from the more than a century of pollution.

REMEMBER WAITING FOR THE BUS? Most areas built before 1950 in the US (now housing roughly one-third of the US population) have seen significantly improved transit service, with real-time information about arrivals and schedules. With more urban residents and fewer cars, the demand for transit picked up. Agencies were able to run more buses with the uptick in demand, further encouraging bus use, and now bus-powered urban transit agencies (some of which have a few legacy rail lines) are one of the few profitable branches of government. New autonomous buses powered by now widespread renewable energy have lowered costs. Transit organizations now see ridership levels they last saw in the

1940s. Buses in the suburbs were canceled though.

REMEMBER SEEING THE HIGHWAY? Without the urban interstate, today's cities would look much different. For freight, we are now in a world with self-driving delivery vehicles and aerial drones that our parents scoffed at. *Through* traffic could always avoid the central city, *to* traffic can be carried on surface streets as needed. Vehicles are considered a nuisance when they are seen or heard, even when they are safe and clean. Today's freeways have been rebuilt as high-capacity tunnels, carrying not-only driverless but especially passenger-less vehicles. Construction of course was costly (and disruptive), but with advances in robotic tunneling technology, further automation, and the right economic model, this was justified in cities across the world.

REMEMBER PARKING YOUR CAR? We eliminated most urban parking lots and garages, both because cars can drive farther away to park, and because shared vehicles can be in motion for much more of the day. Urban space is too valuable to let it be used by idle cars. Cars now drop you off near your destination and go on their way.

REMEMBER FREE ROADS (AND FREE PARKING)? Strangely, we didn't used to charge for the use of roads, or for parking cars, and then complained when roads were congested and people spent minutes cruising around blocks looking for spaces to park their cars. In the early 2020s, the two-decade long decline in Gas Tax revenue due both to declining demand and increasing electrification of the fleet finally enabled the push for mileage fees. With the New Rationalism movement, economists implemented their most cherished idea, and most radical change on society: charging for roads. First it was implemented for the new electric vehicles, which didn't pay gasoline taxes, but then for all cars after EVs came to dominate. By 2025 the government enacted a number of reforms to get the federal government out of local transportation, and encourage states to toll their highways. While gas taxes were eliminated, refinery taxes were implemented. The government also put in place carbon and other externality taxes to replace income taxes. More importantly, agencies implemented off-peak discounts, with higher peak prices. Trips that were not urgent at rush hour on Tuesday, Wednesday, and especially the very busy Thursday afternoon in the summertime turned out not to be particularly urgent at all, and total travel dropped more. These pricing reforms finally drove the knife into the heart of traffic congestion. While

there was grumbling, and a few riots, almost everyone valued their own time more than they realized.

Looking forward, transport academics at the University of Sydney's new Boulder campus foresee that new light-weight robo-copters will make roads and tunnels obsolete, and people will just take off vertically from their driveway or roof, and go anywhere they want. With newly-low cost housing conveniently available in rural areas, maybe living in cities loses some allure, and travel will rise rapidly again.

But no one thinks congestion is coming back; life is too short to waste sitting in traffic.

Part I

History

1

Climbing Mount Auto: The Rise of Cars in the 20th Century



Figure 1.1: Ford Model T.
Source: Wikipedia.

IN THE EARLY 20TH CENTURY, automobile commuters brushed elbows along cluttered streetscapes with meandering pedestrians, righteous wagon drivers, streaming electric streetcars, and antagonistic horsemen. Rutted roads of gravel and dirt posed other challenges. Amidst this chaos, a new prospect was viewed from afar. Spurred by technological innovation, this new vision invoked a radical process to restructure streets, cities, and society.

Governments, consumers, and auto-makers sighted prospects of a

In 1924, a Chevrolet cost \$525. (History 2017) Today a Malibu is about \$20,000. Similarly the wage in 1924 was \$0.56/hour (Wolman 1930) for a manufacturing worker, and today is \$19.70/hour. (Trading Economics 2017) So the number of hours to buy a car has gone from 937 to 1015 (or essentially remained flat). Of course the Chevy today is much better and more reliable; and many more people have higher incomes than manufacturing workers, so more people could afford cars, and so did.

¹ These brief slow downs in the inexorable rise in vehicle travel are usually attributed to the oil supply and price shocks in 1973-4 (Yom Kippur War), 1979-1981 (Iranian Revolution), early 1990s (Gulf War), and early 2000s (9/11).

peak in the distance. Atop it supposedly contained wealth, freedom, happiness, and everything in between.

Henry Ford began rolling a Model T off the assembly line in 1908 in the US. By 1911 one was produced every fifteen-minutes; 1923 saw one every 15 seconds (off of multiple assembly lines). Mass automobility spawned new strategies to reach that peak. The commoner could now acquire a car with four months of work. From the 1920s onward, the automobile was increasingly the dominant mode of travel in the US.

While the Great Depression slowed the auto's growth, it did not result in decline. Despite the brief downturn during World War II and a few hiccups here and there,¹ the pursuit to climb this uncharted territory was resolute. More than a dozen US Housing Acts spread over the 1930s, 40s, and 50s made it easier than ever to buy the pristine suburban home. General Dwight Eisenhower, while serving as Supreme Commander during World War II, witnessed the Autobahn in Germany. Recalling his earlier military convoys across the nascent American highway system after World War I, he recognized the military value of limited access highways. President Dwight Eisenhower helped marshal resources for the US to build a comparable system to that in Germany. The Interstate Highway bill had been mired in Congress for nearly a decade, stuck in debates about how to pay for it, much like his convoy had been mired on the dirt roads and collapsing bridges of post-World War I America. Coupled with policies in 1949 to stimulate 'urban redevelopment,' later broadened in 1954 to 'urban renewal,' monumental changes took root in cities. For Americans, this new roadscape meant accumulating more travel by car than other modes, or than anywhere else in the world.

Tectonic forces reinforced a continued march up what became Mount Auto. These forces include increases in:

POPULATION. As there were more people, there was more collective daily travel to everyday destinations like work, school, and the store.²

WORKFORCE PARTICIPATION. More women started working outside the home.

INCOME. With money, people can satisfy wants in addition to needs, and the means by which that income is acquired (work) required more travel as well.

AUTO MASS PRODUCTION. Ford's process spread widely, thereby

² The population of prime working age peaked around 2000.

dropping the relative price of auto-mobility.

DEVELOPED AREA. Urban renewal gutted blighted and working neighborhoods alike. Metropolitan areas accommodated the automobile, new residential lots (and the houses sitting on them) got bigger. So did shops and offices – all of which were surrounded with parking lots.

ROAD NETWORKS. Roads better accommodated the car by getting wider, sparser, and more tree-like; new limited access freeways were constructed. Cars, and improved transport generally, made it easier for more people to reach more places in less time. By extending one's reach, meant more choices, more specialization, more division of labor and more economic activity. Faster travel and more direct routes are half of this. Where people locate relative to the places they want to go is the other half.

With more people attaining automobility, increasing distances (to attain larger lots and bigger buildings for less money) were compensated by faster speeds. So destinations became less convenient for the carless – the farther things are spread out, the less effective is walking or public transit – and thus making cars even more valuable. The growth in infrastructure supply fed the growth in demand; the ascent to the summit of Mount Auto was relentless.

Evoking the idea perhaps first popularized by Lewis Mumford,³ Tony Downs, in his 1992 book *Stuck in Traffic*,⁴ described what he coined the 'Iron Law of Congestion'.⁵

By expanding capacity (i.e., building a road), much, though rarely all, of the additional capacity gets used in the short term by people switching routes, modes, and time of travel. Longer term impacts (i.e., development or behavior change) further reinforce the phenomenon.

The race to the summit of Mount Auto in the US persisted for almost a century owing the supposed 'joys of automobility'.⁶ But more recently – since the mid 2000s – climbers have been ambling around atop this peak of Mount Auto, asking 'now what?'

Clouds have obscured their vision for years. Reports from the Department of Transportation, at least in the US, say they are losing elevation.

Figure 1.2 reveals that vehicle travel per person dipped for most of the 2000s and the early 2010s (total vehicle travel has dipped too, but not as severely owing to population gains). Per-capita vehicle travel is roughly where it was in the late 1990s and total vehicle travel

³ Mumford's 1955 essay called: "Renewed Circulation, Renewed Life" can be found in the book *The Roaring Traffic's Boom* (Mumford 1955). This title referred to Mitchell and Rapkin's *Urban Traffic: A Function of Land Use* (Mitchell and Rapkin 1954). The more formal name for the Iron Law of Congestion or Triple Convergence is now 'Induced' or 'Latent Demand.' The use of these terms has become politicized. 'Induced' demand implicitly blames the freeway for more congestion. 'Latent' implies the demand was always there, and is now able to be realized. In any case, the whole concept is obvious from a micro-economics perspective. Both phenomena simply move the supply curve down and to the right on a downward sloping demand curve. Traffic engineers typically assume that new infrastructure does not change the demand for which they are designing. Sometimes the discussion is broadened a bit and goes by the 'Cycle of Auto Dependence.' All underscore the same thing. See: (Levinson and Krizek 2007) for a textbook explanation.

⁴ (Downs 1992).

⁵ While the 'Iron Law of Congestion' (induced demand) implies that supply creates its own demand, this is true only to a point, while demand is growing faster than supply can accommodate it. If demand were not supply constrained, as in many rural areas where roads are well-below capacity, there is no induced demand. If demand is falling for other reasons, even if supply is rising, induced demand stumbles. And once maturity has set in and all the low-hanging fruit (high-benefit, low-cost projects) have been picked, the net cost of projects rises, fewer and fewer roads get built.

⁶ Mel Webber wrote a paper "The Joys of Automobility" (Webber 1992) in (Wachs and Crawford 1992) that argued that people rationally preferred the auto because of its flexibility and efficiency.

Figure 1.2: Climbing Mount Auto. The graph shows both linked and unlinked transit trips, as the way transit trips are counted has changed, and there is no continuous series of both over the entire period. Source: (US Census Bureau 1992; Highway Statistics 2016).

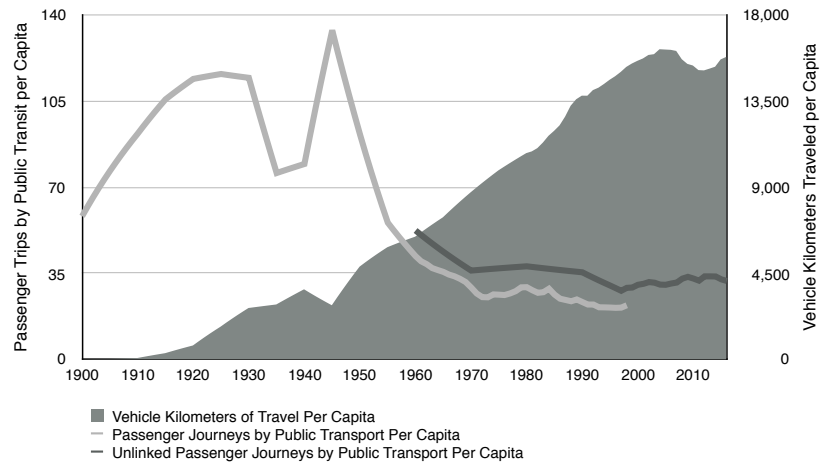
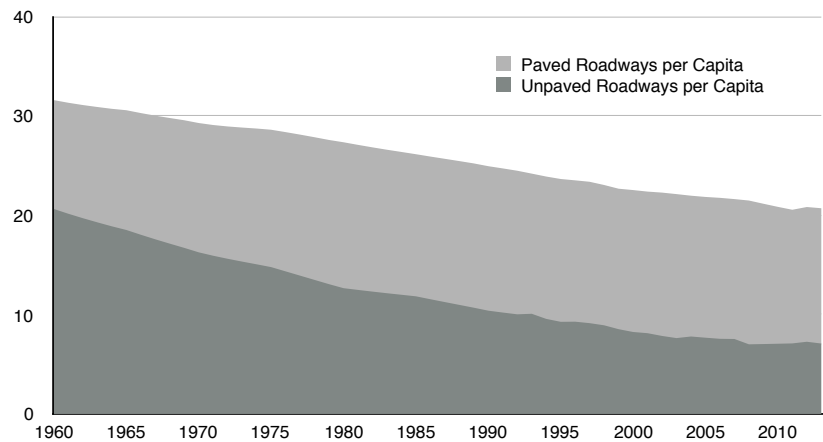


Figure 1.3: Roadways per capita in the United States (m) 1960-2013. Source: Based on (US Bureau of Transportation Statistics 2016).



only surpassed the 2007 peak in 2014 even with steadily increasing population. Context helps put the significance in perspective. These trends follow 90 years of steady, almost uniform increases in the amount of automobile traffic. Barring a few exceptions owing to war, economic downturns, or energy shocks, vehicle travel increased almost every year in the US for the entire twentieth century.

When humans ascend new peaks, it is a celebrated event. For example, during the writing of the first edition of this work, the rock climbing world was in awe witnessing the determination of two individuals, in January of 2015, who became the first ever to free climb the entire Dawn Wall in Yosemite National Park in the US.⁷ Has the true peak of Mount Auto been discovered? Is the decline in car use permanent? Should it be celebrated?

Some transport analysts suggest the peak is similar to what

⁷ (Bisharat 2015).

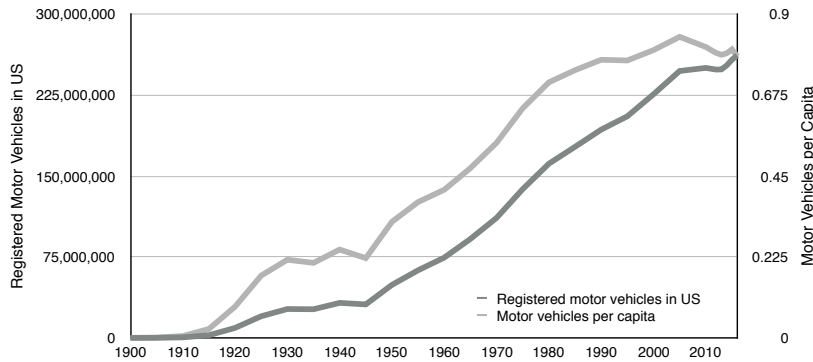


Figure 1.4: Registered motor vehicles in the United States 1900-2016. Source: (US Census Bureau 1992; Highway Statistics 2016). 2012-2016 from (Hedges and Company 2017).

happened to fixed route transit service in the US (which is now well below one-fifth of its previous importance as described in Chapter 12). Others claim it is a brief hiatus from the steady march of increasing per capita vehicle travel that followed the same drumbeat almost continuously from 1910 to 2000. Some call the recent patterns of vehicle travel ‘trendlets.’ But what has gone largely unrealized was that travel began dropping before the economy tanked.

History will be the ultimate arbiter. However, this much is clear: evidence for ‘Peak Travel’ has been mounting.⁸ This does not mean there will never be a year in which car travel again rises (It rose overall and on a per capita basis in 2014-2016, for instance, years with an expanding economy and falling fuel prices). As Figures 1.3 and 1.4 show, car ownership per capita, and paved roads per capita are *also* down.

⁸ (Millard-Ball and Schipper 2011; Metz 2013).

What about other dimensions of what has historically been called travel? The best source for reliable, recent, and aggregate statistics in this regard for the US comes in the form of the American Time Use Survey. This data source, starting in 2003 and for every year thereafter, tallies the amount of time Americans spend in various activities, *including travel for ten different purposes* as shown in Figure 1.5. For a full decade’s worth of data, it draws the same sketch. The amount of time spent in travel has declined six minutes – from 74.4 minutes to 68.4 minutes per day.

And as shown in Figure 1.6, at a more disaggregate level, persons born in the most recent cohorts are traveling shorter distances than people born earlier at the same point in their life. Similarly persons born in the most recent cohorts make fewer trips than persons born in earlier decades at the same age. We are not talking just about Millennials; this is true of Generation X as well.

Almost all things appear to be going down. Little is going up.

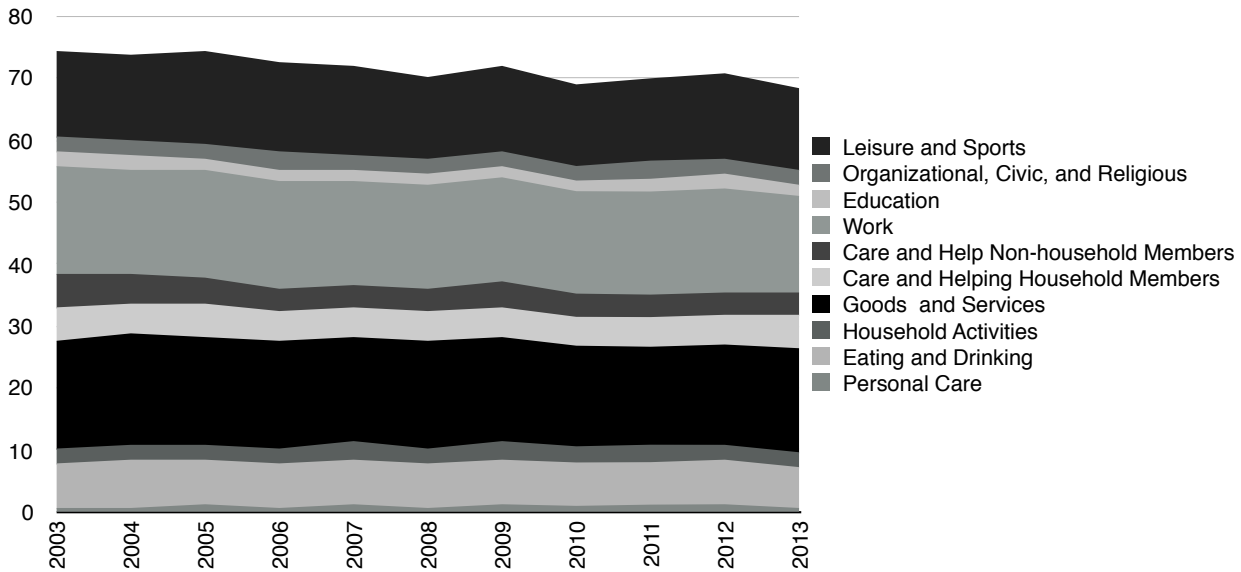


Figure 1.5: Time spent traveling per day by purpose: 2003-2013, Source: (US Bureau of Labor Statistics 2014a).

Data are suggesting that many people are driving less and ironically, Americans are leading the charge in this respect. In the absence of further external events (economic, technological, demographic, or social), the curve appears to have peaked, or at least plateaued.

Does auto-mobility indicate progress? Some economists point to high historic correlations between auto use and economic growth (Gross Domestic Product (GDP)) to argue that a drop in one affects the other. Few people support declining GDP. The transport industry (car-makers, road-builders, service operators) has long insisted that “What is good for General Motors is good for America.”⁹ In short, more is better: more cars, roads, and shipments are all better. On a personal level, many people see less auto-mobility as a threat to their personal quality of life – automobility provides most people with freedom and value – the ability to engage in daily activities at less time or out-of-pocket cost than current alternatives.

These arguments are short lived, however. Those in the transport industry are being slowly (and rudely) awakened from their dogmatic slumber by innovations from outside the sector. There is good reason to celebrate the discovery of the summit of Mount Auto. Not only can the climbers get onto more productive endeavors, but less traffic is good thing. *Economies are changing*. The old standby argument that society requires mobility to fuel economic growth is being undermined. The longtime correlation between GDP and distance traveled has broken.¹⁰ In fact, it would

⁹ More precisely, Charles Erwin Wilson, in confirmation hearings to be Secretary of Defense, said:

“For years I thought that *what was good for our country was good for General Motors, and vice versa*. The difference did not exist. Our company is too big. It goes with the welfare of the country. Our contribution to the nation is considerable.”

¹⁰ (McMullen and Eckstein 2012; Badger 2015).

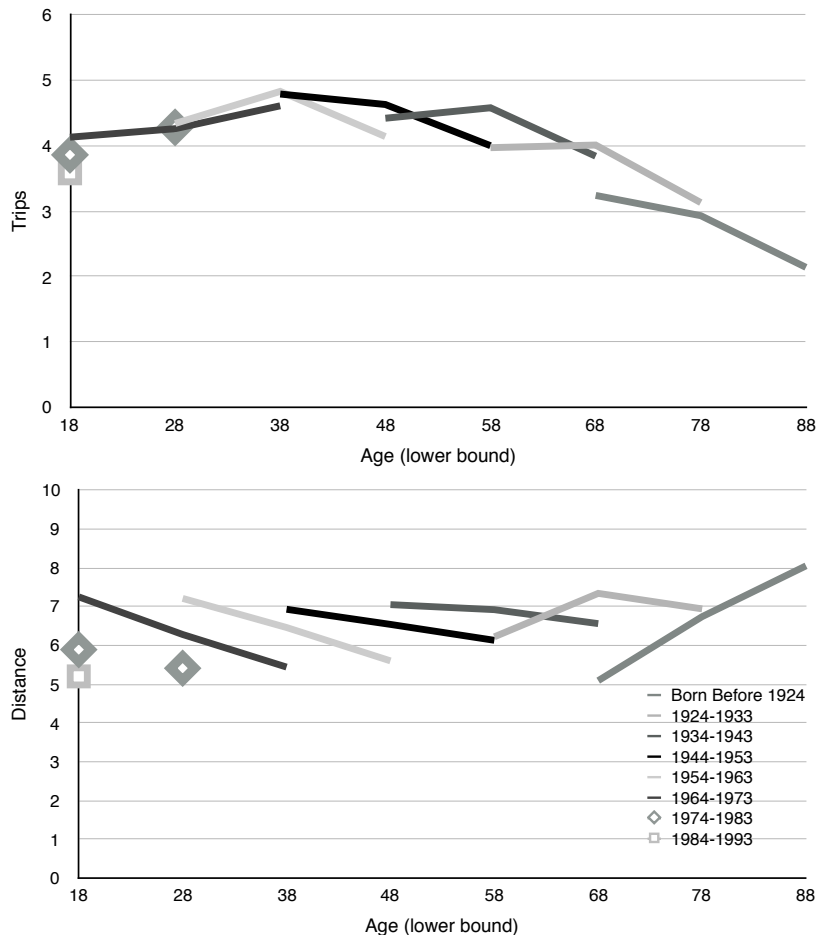


Figure 1.6: (top) Person trips per day, (bottom) Average trip distance, by age and year of birth. Source: (Iacono and Levinson 2015).

be quite depressing if it were otherwise, indicating that society cannot make the economy more energy-efficient or time-efficient.

NEW TRANSPORT PATTERNS ARE TAKING ROOT. If only there were a single possible significant technological or social shift, these changes might be predictable. But most societies, at least most those who have been industrialized for some time, are currently dealing with several – and simultaneous – shifts in play. Perched from the vantage near the Peak of Mount Auto, both technological and social forces clouding a view of a prospective Mount Next.

THERE IS A CONVINCING SIGNAL THAT DRIVING, TRAVEL, AND TECHNOLOGY ARE BEHAVING DIFFERENTLY. Technology has devastated many industries. Remember, back in the day, when print newspapers, travel agents, post offices, record albums, paper books,

land-line phones, and broadcast television mattered? We do not claim that technology is devastating travel in exactly the same way. Quoting Mark Twain, "History doesn't repeat itself, but it does rhyme."

Rather, technology is restructuring transportation in ways different from the past. There is always more to the story. In the end, *traffic* – and *the automobile regime* – as most have come to know and both love and hate it, are *both* demonstrating considerable signs of instability. A death may be coming. Just as cars rose to greatness in 20th Century America, it appears as if they are now experiencing wounds from several daggers.

2

Less Traffic is a Good Thing



Figure 2.1: Multimodal environments, even with separated bicycle facilities, tend to favor the automobile, as in this scene from Medellín, Colombia. Photo by Kevin J. Krizek.

MY AUTOMOBILITY IS YOUR TRAFFIC. And, if demand (the number of cars making trips) outpaces supply (the amount of roadway available), then congestion results. Such dynamics are efficient to a point; they help spread the cost of road construction and maintenance over more drivers. In the absence of any other drivers, you would not enjoy a road network. Exceeding a threshold, however, congestion kicks in, causing delays. The most widely experienced negative outcome from auto-mobility within the transport realm is wasted time. But angst, frustration, and of course, being late for dinner are other effects.

More generally, using cars imposes negative costs beyond

Our colleague Julian Marshall reminds us:

“Just as estimating deaths from air pollution is inexact (no death certificate says ‘air pollution’ as cause of death; instead rates of outcomes like heart attacks are elevated slightly in the presence of air pollution), so too it is inexact to estimate contributions from specific sectors (e.g., road transport) to the air pollution total. Some PM_{2.5} is emitted directly and some pollution forms in the atmosphere from chemical reactions of precursor emissions; the latter type (called ‘secondary PM_{2.5}’) is harder to attribute.”

Table 2.1: Deaths per 100,000 people.

Annual	Transport	Pollution
Deaths	15	36
Years lost	653	565

Units: Deaths per year per 100,000 people.

Pollution: Deaths due to ambient particulate matter and Ozone, not just transport-related pollution deaths.

Transport: Deaths due to road injury plus other transport injury and is comprehensive. This includes things like driving off a cliff as well as driving into pedestrians.

¹ (Global Health Observatory 2010).

² (Economist 2014) discussing our colleagues’ work (Tessum et al. 2014).

³ Recycled tires go to many different places, such as being recycled into furniture or balls or astroturf, in addition to being burned, but the rubber that just wears off your tires is pure pollution.

⁴ (IHME 2014).

inconvenience for the carless and congestion for the motorist. In economic terms, we refer to this as the *full costs of travel*. The *full benefits* are largely internalized, those who travel get them. The costs are partially internalized – travelers pay for their own time, their car (which is often a significant share of income), their gasoline, their insurance, and some of the cost of infrastructure. Drivers don’t pay for all of the cost of roads and bridges just as transit fares don’t cover the cost of transit service. Additional externalities are not fully accounted for by drivers when traveling.

Below we outline arguments that demonize cars – arguments that the two of us have heard over the past two decades. While all costs need to be considered with offsetting benefits, from our current position, we explain why a community – your community – with fewer cars and less traffic is better.

CARS CRASH. Cars collide – with each other, and crash into pedestrians and bicyclists and buses and trains and inanimate objects, and just about anything you can imagine. These crashes still kill over 30,000 Americans (and over one million people globally)¹ each year, and maim countless others. The numbers in the US have declined significantly for a variety of reasons: better cars, better emergency response, less drinking and driving, better roads, but are still too high. While most fatal car crashes are not during congested periods, congested traffic goes slower and thus cars are less likely to collide at high speed, crashes do rise and fall with the number of cars on the road, and are a source of what the industry calls ‘non-recurring’ congestion, compared to the daily ‘recurring’ congestion because too many cars are trying to use the same road at the same time.

CARS POLLUTE. This is mostly a consequence of the present engine technologies based on the internal combustion engine and the type of fuel used. However, electrification of the fleet without simultaneous conversion of electric generators to clean or renewable sources may be counter-productive.² Estimates of deaths from motor vehicle pollution are on the same order as the number of fatalities from crashes now, although the deaths due to pollution affect a different segment of the population, disproportionately the old and the young, see Table 2.1. There are other sources of pollution besides the tailpipe. When your tires wear down, where does all that worn out rubber go? (Hint: you might be breathing some of it).³

The Global Burden of Disease Study⁴ for 2010 produces the

results shown in Table 2.1. Those numbers include only fine particles (PM_{2.5}) and ozone. Using those numbers, air pollution is worse than crashes in terms of total deaths, but not in terms of years of life lost. Car crashes are feared more than air pollution from traffic, but emissions are not something to be sanguine about.⁵

NOISE ANNOYS. All noise has real economic, physiological and mental health effects; the effects of car noise tend to be even more acute. Hundreds of studies confirm that prices for homes near freeways (and airports) are lower than otherwise similar homes farther away, suggesting the damage of noise pollution.

CARS ISOLATE. From spatial, psychological, and equity perspectives, cars isolate people more than other modes.⁶ Straightforward geometry suggests that lower development densities prompt more driving between destinations and lower accessibility for modes like walking. From an equity standpoint, the argument is more clear. The land use structure in many suburban communities, for example, favors car use, which is more expensive than other modes. This prices out some who become the carless. Thus, an auto-dependent land use system makes driving a necessity; it has even been thought of as a right, not to be lightly taken away by municipal court. Automobiles stratify society and exclude the less mobile.⁷ Psychologically, cars effectively put a barrier between the user and the environment. The enclosure of the car physically isolates the driver from her surroundings. Some cities have become so stratified that mass transit is the only space where individuals from different socio-economic strata cross paths.

CARS CONSUME LOTS OF SPACE. One estimate of the total impervious surface (primarily roads and parking) in the US puts it at 43,000 squares miles (111,000 km^2), just a bit smaller than the state of Ohio (Figure 2.2).⁸ Paved area has environmental implications: less pervious surface to filter water, more pavement to absorb heat; direct costs: paving roads and parking, asphalt and concrete production and construction; and opportunity costs: land that is paved for roads and parking cannot be easily used for something else, money spent paving that land cannot be used for something better.

ADVANCES IN TECHNOLOGY WILL WEAKEN SOME OF THESE ARGUMENTS ABOUT LESS TRAFFIC BEING A GOOD THING. We discuss some impacts in later chapters of this book. Information

⁵ An MIT study comes up with more annual deaths from air pollution at about 200,000 per year in the US (rather than the 100,000 or so the GBS study implies). Air pollution deaths (premature strokes, heart attacks, lung problems, and so on) on average shortens life by 10 years per person who dies from air pollution. Car crashes are more likely to shorten life of younger persons, hence the greater years of life lost per death. See (Caiazzo et al. 2013). Our temperaments of course are affected by the air we breathe.

⁶ While fully acknowledging that, given the prevailing land use structure in most communities, cars serve the principle means of connectivity.

⁷ (Preston and Rajé 2007).



Figure 2.2: The state of Ohio is equivalent to the paved area of the United States. Source: Wikipedia.

⁸ (Frazer 2005).

technologies and new economic models of car use and ownership, transit use and ownership, and road management and ownership will allow cities to be more efficient using fewer resources: fewer cars, less pavement, better capacity utilization, less need to travel in the first place, and new (old) models of logistics.

3

What Killed America's Traffic?

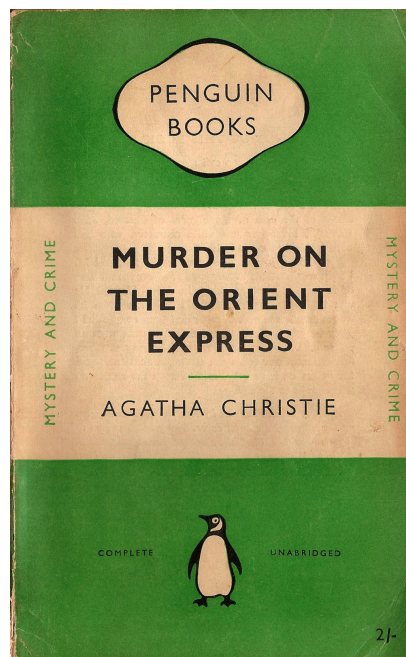


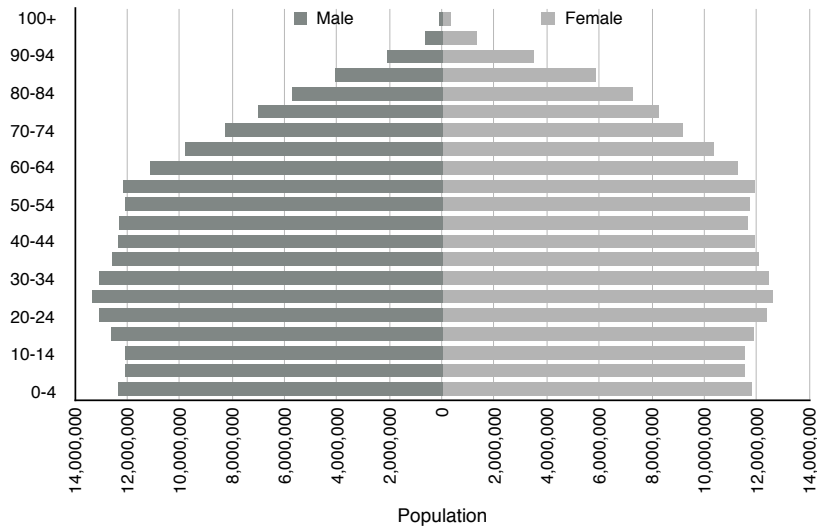
Figure 3.1: *Murder on the Orient Express*.

In 1934, popular mystery writer Agatha Christie published *Murder on the Orient Express*.¹ To spoil the ending, she places the responsibility of one man's death not on the shoulders of a single individual, but rather, atop the shoulders of many. Some transport analysts attribute the changes to per capita travel demand to changing levels of employment and fuel prices. Further, the slower rate of road construction limits the amount of induced demand that may have driven travel growth earlier. Such reasons, certainly, are part of the whole package, but they cannot explain everything. Like Christie, we charge several culprits who have cumulatively contribute to the crime of 'killing,' or at least maiming, traffic.

¹ (Christie 1934).

3.1 Changing Demographics

Figure 3.2: Age pyramid in US 2014. Source: (Rogers 2016).



² It is important to recognize there is no official definition ‘generations,’ and different analyses use different time periods. Our usage is defined by consistent 20 year periods. The term ‘Generation X’ was popularized by Douglas Coupland in an entertaining book of the same title. (Coupland 1991).
³ (APA 2014).

⁴ (US PIRG 2014).

Both Kevin and David are Generation X (born 1964-1983)² – a group that has *not* radically affected aggregate transport behavior. But the two generations flanking us – historically the two largest current demographic groups in the US (see Figure 3.2) – are now helping to diminish driving. These groups have received the most attention in discussions about travel and the future of cities.³ Millennials (or Generation Y) (born 1984-2003) are America’s largest generation. It is larger in number than the Generation X cohort that preceded it and decidedly more diverse (less white) than any American generation that has come before, with a larger share of immigrants. As with all generations, Millennials carry new attitudes about communications, sharing, and urban lifestyles. Relative to previous generations, they are objectively less car-focused;⁴ their transport behaviors reduce driving.

The Baby Boomers (born 1944-1963) now comprise a slightly smaller share of the population than their children and grand-children. They have been emptying their nests for years now and are slowly dying off. The extent to which they move to central cities as opposed to staying in place or retiring elsewhere remains to be seen.

Aside from strict socio-demographics and emerging preferences, there are other changes that are more surprising. Many US central cities, downtowns in particular, are gaining population again after a long period in the mid-late twentieth century of depopulation.

Why? Some say it is just generational, Millennials have different preferences from their elders. As younger (middle-class) people defer procreation for recreation, living in the central city is easier. To be clear though, while population growth in the urban core may be higher in percentage terms (than it was and than the suburbs), it is still smaller than suburban growth in absolute terms, owing to the suburbs' much larger base.

Most cities, at least in the US, are now more pleasant than just ten years ago. Such progress has less to do with urban policy, and certainly ought not be attributed to economic development officials penchant for convention centers, festival marketplaces, stadiums, and streetcars. Rather, it is more associated with environmental policy and technology, as well as drops in violent crime. Cities are more entertaining as well, there is more to do. In the early twentieth century, people fled over-crowded cities for suburbs in part because of poor environmental quality. Relative to a century ago, water quality in cities has significantly improved, sewers are sanitary, and horses no longer befoul the streets. Air quality has also steadily improved since the late twentieth century. Lower density areas still claim the upper hand over cities when it comes to air quality.⁵

Furthermore, the culture just may be different. The desire for mobility, especially auto-mobility has dropped, as today's youth apparently prefer to spend their disposable income on the latest internet-connected gadget (unlike older generations?), according to a 2012 survey by Zipcar.⁶ The degree to which this is making a virtue of necessity – perhaps Millennials cannot afford cars and fuel as easily as older, more well-situated, generations, and so choose to embrace their relative poverty – is unclear, though demographics, attitudes, and other external factors all play a role.

According to Noreen McDonald:

“Among young adults, lifestyle-related demographic shifts, including decreased employment, explain 10% to 25% of the decrease in driving; Millennial-specific factors such as changing attitudes and use of virtual mobility (online shopping, social media) explain 35% to 50% of the drop in driving; and the general dampening of travel demand that occurred across all age groups accounts for the remaining 40%.”⁷

Others attribute much of the change to the economy, and less to preferences and generational shifts.⁸

⁵ This has health effects, the beneficial effects of greater walkability (and thus walking) in urban centers is offset by the additional pollution intake in those same places. (Hankey et al. 2012).

⁶ (Zipcar 2013).

⁷ (McDonald 2015).

⁸ (Blumenberg et al. 2012).

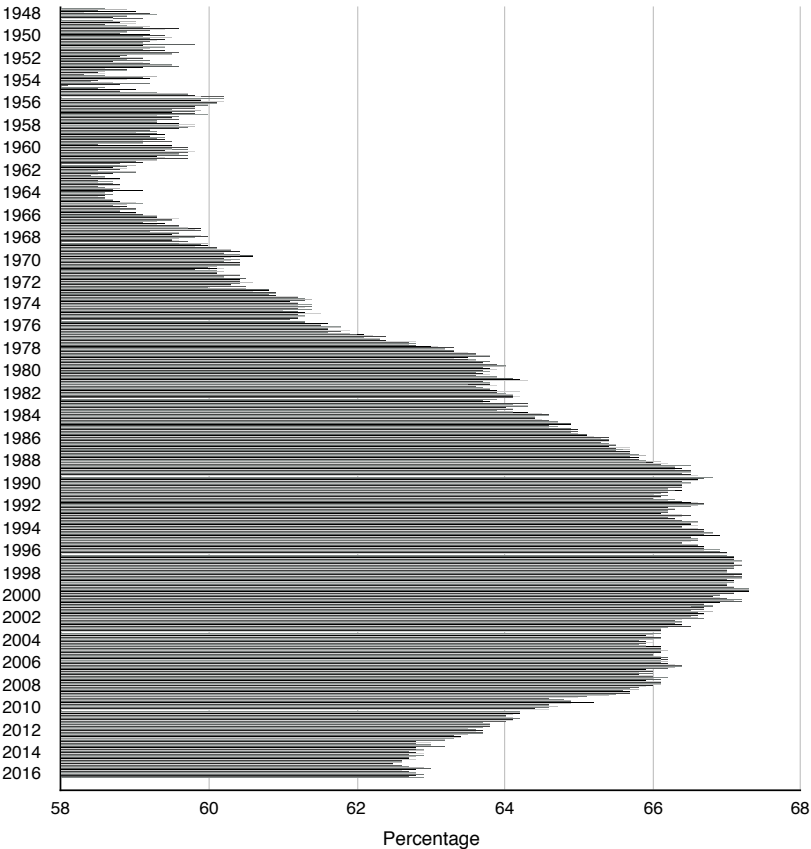
3.2 Changing Nature of Work

Figure 3.3: US labor force participation rate: 1948-2017. Source (Bureau of Labor Statistics 2017).

The *Economic Report of the President* 2015 writes: “Overall, the most important factor affecting the aggregate participation rate in the recession and recovery has been the aging of the population. But there are a number of important trends and developments relevant for understanding the changes in participation of different subgroups of the population:

- Increased participation by older Americans, which may be attributable to an increase in skills among this population and also to changes in Social Security retirement benefits;
- Reduced participation by younger Americans as they stay in school longer;
- Continuation of an at least 65-year long trend of declining male labor force participation, which is especially stark for young minority men; and
- Tapering of the long-term trend of increasing female labor force participation, which dates back to before World War II.”

(The White House 2015).



The workforce in the US has continued its drop as technology-enabled productivity reduces the economic value of older and unskilled workers. While the total size of the workforce is, at this writing, higher than it was at the depth of the Great Recession, a smaller share of the working age population works today. Fewer people are traveling for work, and fewer discretionary trips are made by both workers nervous about spending money and the unemployed who have fewer resources to spend. Starting in 2008 in the US, unemployment increased sharply, and though it has since declined, employment participation rates remain much lower as shown in Figure 3.3

Demographics are also part of this. Many employees have dropped out of the labor market as their skills have been devalued by the economy; older workers are choosing, or having imposed on them, early retirement, while younger workers are deferring entry

into the workforce, choosing to accumulate more education.

The rise in female labor force participation from the 1930s through the 1990s has also run its course; labor force participation is roughly equal by gender.⁹ The percentage of women in the workforce has plateaued since the turn of the century. The percentage of men has dropped.¹⁰ There is no indicator suggesting that this is likely to reverse significantly, and certainly not pass the previous peak.

Americans now work fewer hours over their career than their working grandparents, and probably their parents (for annual hours, see Figure 3.4), which shows little change over the past 7 decades). They start their careers later, extending the pre-work period into their twenties, taking advantage of productivity gains of parents and ancestors, and borrowing against future productivity. They also retire earlier, post-work retirement starts into their fifties, reaping the rewards of our collective productivity. Vacation time has not changed much in recent decades.

Travel patterns differ by age group. One thing is for certain: those who do not work daily do not make work commutes daily. While some of the now available non-work time is made up with out-of-home activities requiring travel, that does not require peak hour travel, and so imposes fewer stresses on the transport system.

⁹See: US Department of Labor - Women's Bureau (n.d.) *Women in the Labor Force in 2010*. <http://www.dol.gov/wb/factsheets/Qf-laborforce-10.htm>.

¹⁰Even recent decreases of labor force participation are a consequence of productivity gains among those remaining, as the long-standing connection between productivity and workforce participation has severed. People may be more willing to remain unemployed looking for the right opportunity, than to take any job that happens to be available. Because of its higher productivity than decades ago, society can afford more unemployment and underemployment rather than matching people to jobs they may be less than optimally suited for. The economic shock of 2008 broke many old arrangements, and the economy is still sorting out the effects.

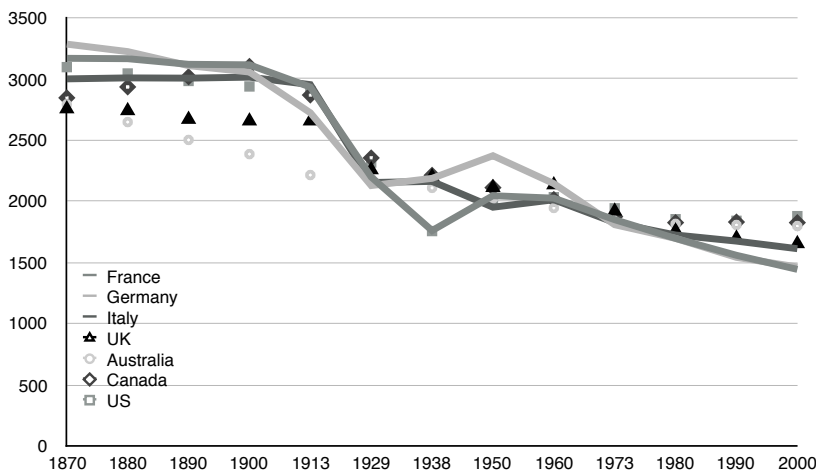
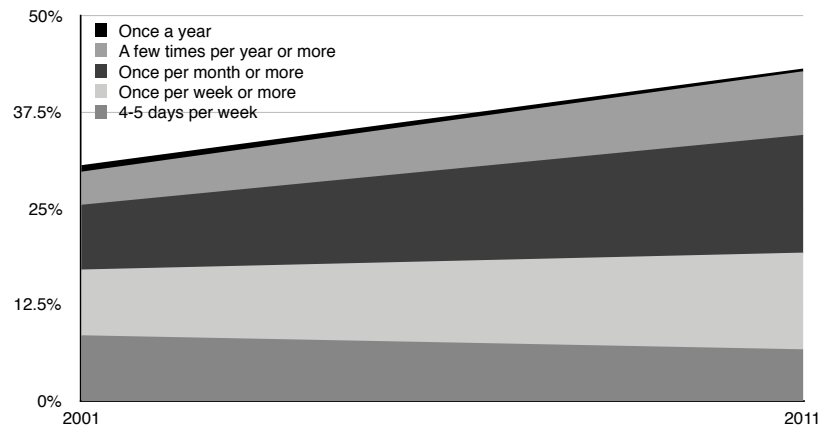


Figure 3.4: Annual hours of work: 1870-2000. Source: (Huberman and Minns 2007).

3.3 *At-Home Working*

Figure 3.5: Telecommuting in Minneapolis- St. Paul Region 2001-2011. Source: Cao in (Levinson et al. 2015).



Modern economies increasingly work with information, thereby loosening the need for physical proximity. While Information and Communications Technology (ICT) is a broad term encompassing a broad category, it is fair to say what used to require physical travel has diminished. There is reduced need to be in particular places to get work done; and, there is nothing magic about the five-day workweek. Both are relics of the industrial age.

The amount of nonwork travel by those who work at home is now greater than that of commuters. By relaxing the amount of commuting, this increases the amount of other types of travel. It is likely that communications and information technology serve as both substitutes and complements transport at the same time. However, while the substitution is direct (more time communicating means less time traveling), the complementarity is due to a reduction of the constrained resource, the time available for nonwork travel (When information technology reduces the time spent at activities with information technology, it means more time is available for other things). The adoption of personal computers and related technologies in the home in the 1990s appeared to follow the emergence of the same on the desk of nearly every office worker in the 1980s. By 1994, home computers were found in 32 million United States homes, and almost 7 million home computers were sold each year.¹¹ These levels pale next to the rise of the Internet beginning at that time and mobile computing in the early 2000s. People were optimistic about the potential of telecommuting.

As computers and related telecommunication technology are necessary, if not sufficient, criteria for performing office work at

¹¹ (Bryant 13).

home, this trend of technology adoption should enable an increase in the amount of work at home. Yet clearly, for most people (or their employer), present technology does not allow working at home to be a perfect substitute for office work. Communication is still slow or expensive. Video, while significantly improving, remains choppy except on dedicated connections.

The opposite hypothesis states that technology will encourage workers to spend more time at the office. Businesses adopt advanced technology earlier than homes, so being away from the office will present a disadvantage. If the power of technology is growing at an accelerating pace, the technological capabilities of the home will fall farther and farther behind that of the office.

Both hypotheses could hold if technology increases the amount of work, rather than reducing it.¹² Some at-home work is in addition to that in the office, while other at-home work can substitute for a trip to the office – technology and employer attitude influence both of these kinds of work.¹³ Telecommuting continues to rise, more as a complement to office work than a substitute (e.g., to check email upon awakening or going to sleep), but even as the occasional substitute, people can work from home either sometimes or regularly.

Figure 3.5 shows daily telecommuting dropped in the past decade (2000/01-2010/11) according to a recent survey in the Minneapolis-St. Paul region, but non-daily telecommuting (once a week or more, once a month or more) rose. In contrast, the US Bureau of Labor Statistics' Time Use Survey reports:

"In 2014, on days they worked, 23 percent of employed persons did some or all of their work at home, and 85 percent did some or all of their work at their workplace, ... In 2003, the first year for which comparable data are available, 19 percent of employed persons did some or all of their work at home, and 87 percent did some or all their work at their workplace on days worked."¹⁴

Enabling factors such as broadband internet, ubiquitous mobile smartphone technology, and employer attitude are necessary for significant amount of at-home work. The tax code, at least in the US also helps. Taxpayers can write-off home offices for part-time at-home work. Employers get taxed for office space. There has been corporate resistance, especially at declining companies, as it is a relatively easy way to reduce the labor force – return to the workplace or lose your job – knowing some workers won't for personal reasons. Former Yahoo CEO Marissa Meyer (of the formerly independent internet pioneer Yahoo) ended the company's work-at-home program before they were sold, as has Best Buy.¹⁵

¹² Schor claims that the amount of time spent at work per worker per week steadily increased in the latter half of the twentieth century. This contrasts with Figure 3.4. (Schor 2008).

¹³ An implication of the influence of information technology on travel demand is that it calls into question whether transportation is separable from other aspects of the economy in both monetary and activity/time use analysis. This assumption is often made, travel demand models rarely incorporate non-transportation factors except for some macroscopic income indicator. But if communication can substitute for transportation, this aspect needs to be considered.

¹⁴ (US Bureau of Labor Statistics 2014a).

¹⁵ (Bednarz 2013).

Relative to the 1990s, high quality, inexpensive, point-to-point video-conferencing is widely available, also with relative instantaneous transfer of data. It is still not good enough though, due both to standards (real-time video-conferencing should have higher priority than downloading torrents of movies), and more importantly, less than full deployment of broadband communication in the US. Even so, like roads, demand will eventually expand to fill whatever supply internet service providers deploy.

Thus video-conferencing has yet to cause at-home work to overtake commuting for even the majority of office workers. It is not expected that these technologies will have much effect for most non-office workers (about half the US workforce), though other technologies may.

Further technological advances may increase or decrease the quality of the home as a workplace relative to the office. If the technology at an outside office remains significantly better than at home, little progress towards an increased share of work at home may be made. Technology adoption typically follows an S-curve, with slow adoption initially until a threshold is reached, increasing steadily until some saturation level. While increasing market penetration of desktop and mobile computing along with the Internet might slightly affect these trends, it is clear that those who wish to work at-home will be early adopters of advances in these technologies.

Nurses, construction workers, teachers, factory workers, farmers and the rest of the non-office workforce may get disrupted by robotics, information technology, and the like, but since their job is not simply pushing bits (though that is certainly part of it), being somewhere in particular will remain important.

Our colleague (Jason Cao) writes, "Although coffee shops have become a new workplace for many workers, they are not expected to materially influence vehicular travel, similar to neighborhood telecenters. In particular, workers at neighborhood telecenters tend to have a higher number of return home trips and other non-work trips on telecommuting days and they also tend to shift from other modes to driving alone."¹⁶

¹⁶ Cao in (Levinson et al. 2016), citing (Balepur et al. 1998).

3.4 Online Shopping

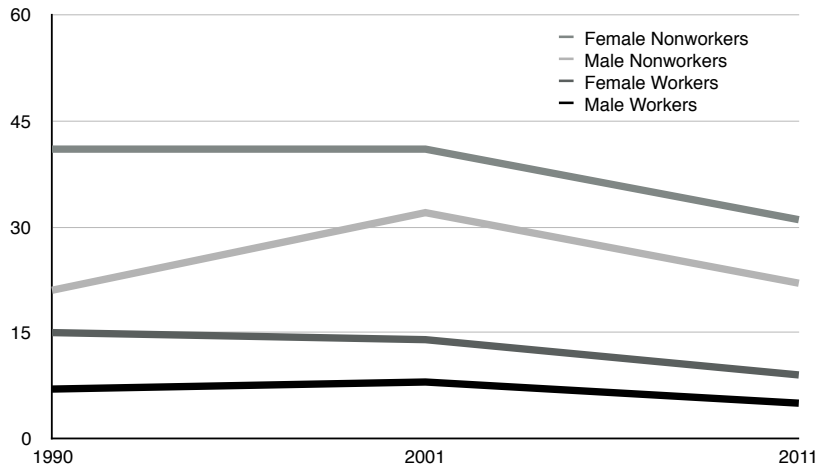


Figure 3.6: Time spent shopping per day in Minneapolis St. Paul region (minutes) 1990-2011. Source: Data analyzed in (Levinson et al. 2015).

The rise of online retailing allows people to substitute delivery for fetching, and reduce the amount of shopping trips. We both remember our parents schlepping us to Sears and Montgomery Wards, but many people would also order from the *Sears Wish Book* or other catalogs, especially around the holidays. The logistics was powered by the US Post Office's Rural Free Delivery, the fastest affordable supply chain of the time. Over the past two decades catalogs have been slowly replaced by the Internet, seemingly a case of the old being dismissed by the new: Sears by Amazon. Notably, Sears phased out its *Big Book* in 1993 and started shrinking its *Wish Book* that same year.¹⁷ Amazon was founded in 1994. But more than just replacing catalogs, online shopping has replaced in-person shopping to a growing extent, and delivery is replacing fetching.

Estimates of e-commerce vary widely. For US retail sales, shares range from 6%,¹⁸ or 7%,¹⁹ to 12%²⁰ depending on definitions (excluding food and car sales would make the share higher). E-commerce sales in the US totaled \$305 billion and were rising about 15% per year in 2014 (while retail as a whole rose about 4%).²¹ Only England and China score higher in terms of percentage of online sales. Not only can shoppers do the same thing differently (and better), they can do many more things enabled by the technology of the web. Amazon, which now claims 1% of total retail sales in the United States, has become the single one-stop shop for everything. Given that Amazon is now over twenty years old, it is hardly considered new anymore. However, its influence on how people 'go' shopping is now unparalleled.

¹⁷ (philly.com 1 29).

¹⁸ (US Census Bureau 2014).

¹⁹ (eMarketer 2013).

²⁰ (Center for Retail Research 2015).

²¹ (US Census Bureau 2015).

²² Shopping trips based on analysis of The Travel Behavior Inventory from the Twin Cities (Minneapolis and St. Paul) in Minnesota (US), see: (Brosnan and Levinson 2015).

²³ (Johnston 2015).

²⁴ Sources dispute what is the busiest shopping day, ShopperTrak says it is Black Friday. (Shoppertrak 2016).

²⁵ (McKenzie 2015).

²⁶ (Banjo and Fitzgerald 2014).

Shopping trips are down by about one-third in a decade, they now comprise fewer than 9% of all trips, down from 12.5% in 2000.²² Time spent shopping per day is also down (Figure 3.6). Other evidence for this trend comes from the UK, where sales of vans used for home deliveries are at a record high.²³

There is further anecdotal evidence of these trends. On Black Friday (the day after Thanksgiving in the US, reportedly the busiest shopping day of the year)²⁴ the community around the non-profit Strong Towns goes to major shopping areas and photographs mostly empty (over-built) parking lots, as shown in Figure 3.7. Cities like Minneapolis are beginning to relax and eliminate minimum parking requirements,²⁵ though the market may continue to overbuild parking for years to come.

More significantly, peak-season (Christmas) retail travel has fallen off a cliff. Total retail foot traffic for November and December 2013 was at 17.6 billion trips, down from about 33 billion in 2010, just 4 years earlier, according to data the Wall Street Journal obtained from ShopperTrak.²⁶ Clearly the rise of the tablet has facilitated shopping via couch rather than car. Assuming parking lot use is an approximate surrogate for the overall health of physical retail, it is becoming clear that physical retail should visit the doctor.

We discuss this further in Chapter 11.

Figure 3.7: East Brainerd Mall on Black Friday (28 Nov 2014). Photo by Charles Marohn. Other photos were posted to Twitter using the hashtag #BlackFridayParking. A montage of such photos can be found on Storify <https://storify.com/yangbodu/blackfridayparking>.



3.5 Virtual Connectivity

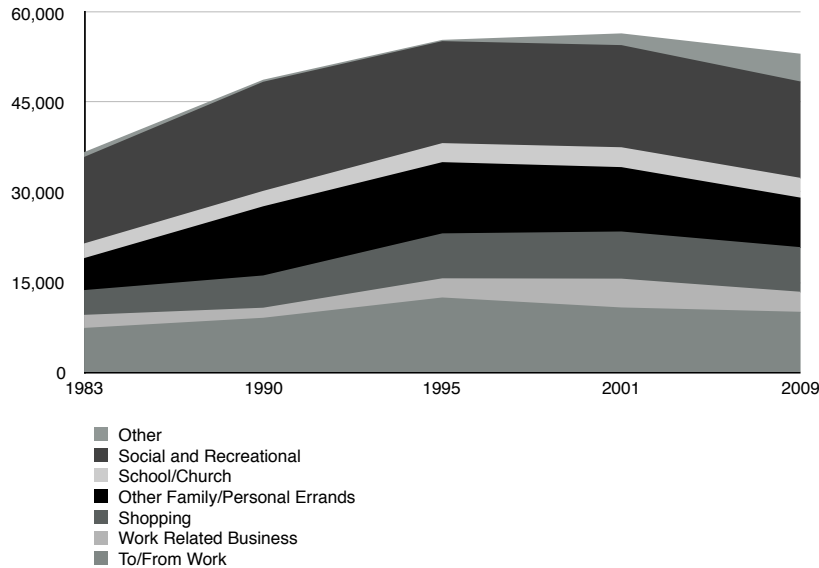


Figure 3.8: Travel by purpose per household (km) 1983-2009. Source: (National Household Travel Survey 2010) Table 5.

It is now easier to virtually communicate with friends, in real-time and asynchronously, regardless of physical location. Social groups more easily grow and shrink with an evening out, as people can know where others are.

With his family, Kevin lives close to the off-campus student population of the University of Colorado who have many parties. But in contrast to the college parties back when he went to Northwestern University, these parties may last mere minutes. Owing to the availability of instantaneous information, students know which location is better, bigger, louder and is currently holding beer-pong championships. Parties today start and end much quicker. Party-goers migrate like ants to the best venue, alcohol acting as a pheromone.

As with at-home work, mobile social communication is playing out in at least two (semi-contradictory) ways. On the one hand, communications can act as a substitute for physical presence. If I am always connected to my friends and co-workers, seeing them in person may be less critical, since the information exchange is continuous. On the other hand, communications and transport are often seen as complements, as mobile communications enable dynamically planning meetings, for instance when two friends discover electronically they are physically nearby, maybe they will meet up, whereas before they would never have known (or not until

after the fact) they were in about the same place at about the same time.

Twenty-five years ago there were approximately no internet users outside of information technology organizations. Five or so years ago, it was easier to conceive of what it meant to be ‘online’ – an amount that bumped up against 40 hours per month.²⁷ Its ubiquity today suggests people with smart phones live in an ‘always-on’ world.

²⁷ ‘Canadians clocked an average of 45 hours online in the fourth quarter of 2011 (CBC News 2012).

The evidence now shows people visit friends less. While we don’t know for sure that the internet prompted this, time online continues to rise, especially mobile.²⁸ Time spent socializing off-line has dropped about 8% in less than a decade, from over 40 minutes per day in 2003 to 37 minutes in 2011 according to the American Time Use Survey. As shown in Figure 3.8, recession impacted or not, the National Household Travel Survey finds social and recreational travel has dropped markedly in absolute terms from 1990. While lack of work obviously crimps work travel, the lack of work in principle frees up time for non-work travel, particularly things like visiting friends.

²⁸ (Wallsten 2013).

Social travel is less structured than commuting. It varies not-only between people, but varies for the same person from day-to-day and week-to-week, and depends not only on the traveler, but who she is meeting. Such social connections are typically at varying locations as well. The regularity of social meetings, especially non-family meetings, results from the fixedness of other schedules due to work and school and other constraints. Something, and technology is a good guess at a major factor, is changing how people engage socially.

We don’t claim face-to-face interaction is entering the dust-bin of history. But the changes are real; and they are large enough to measure statistically, but not so profound they are obvious to everyone. Technology is not (yet, if ever) a full substitute for the environment and benefits that in-person sharing of the same physical space can achieve. People still like to talk to others with human heartbeats in presence. New wearable devices like the Apple Watch, with ‘taptic feedback’ have virtualized that too.

3.6 A License to Roam

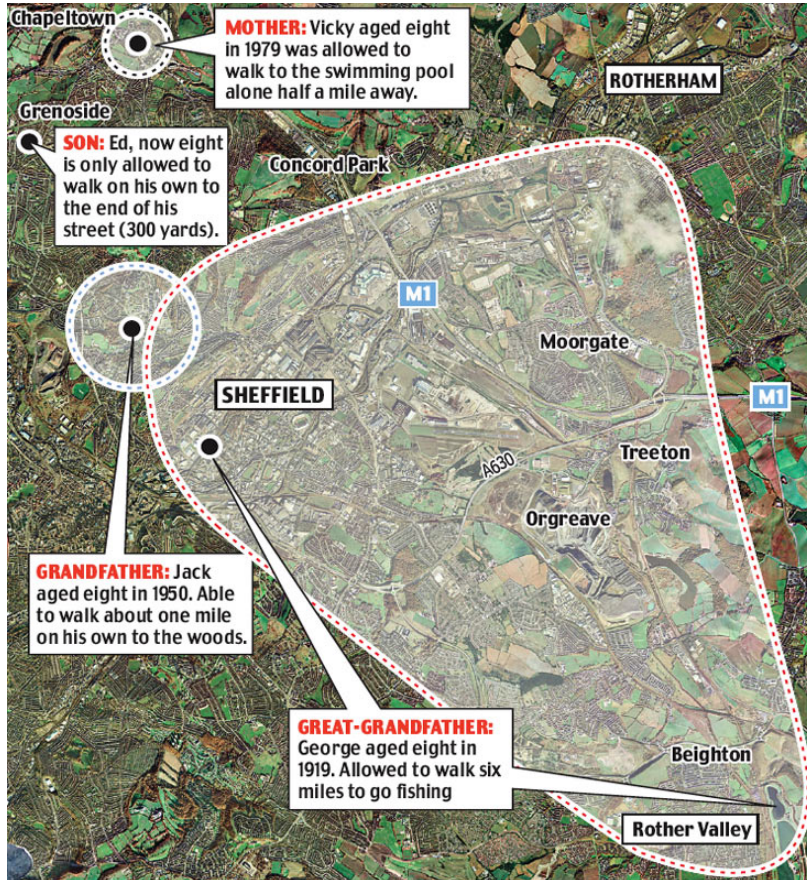


Figure 3.9: Roaming territory over four generations. Source: (Derbyshire 2007).

Despite living less than 20 yards from Kevin's 6th grade classroom, he set the school record with 33 tardies. Some call it lack of parental guidance; others call it free-range child rearing. Life in the 1970s (and earlier) was different. In kindergarten both David and Kevin meandered alone in their neighborhood. By 3rd grade, they cycled across town. By 5th they rode the public bus to the local mall. They were not alone, as shown in Figure 3.9. Yet, parents in a suburb of Washington, DC were recently accused of child neglect for allowing their 6 and 10 year old kids to roam free; the children were taken into the custody of Child Protective Services after another citizen reported them as vagabonds.

Free range kids²⁹ are thwarted because such freedom has vanished and the prison of home is much more enticing. Pulling kids home, television, video games, and the Internet provide far more and far better at-home entertainment options than were

²⁹ (Skenazy 2009).

available when there were only ABC, CBS, NBC, PBS, and an independent UHF channel visible through the static. Pushing kids away from freedom, practicing pop sociology, one can attribute to living in a more fear-based society. Nine doors down the street from Kevin's current home in Boulder (in the opposite direction from the partying student population) lies the famed JonBenet Ramsey house. The Ramsey event, in addition to the Atlanta Child Murders, the Missing Kids on the back of milk boxes, Adam Walsh, and Amber Alerts, make child kidnapping appear more common than it was before or than it really is. Couple this with the decreased number of children per family, we observe children, in contrast with material goods, are far less disposable than they were in our grandparents generation.³⁰

³⁰ David's paternal grandmother had 9 siblings. That is much rarer today.

³¹ Wearing a seatbelt habit formed not just because it was good sense, but because of the seat-belt ignition interlock on 1974 model cars, like David's mother's accursed Chevy Vega, prevented the engine from starting without seat belts. This was a one-year experiment reviled by the driving public.

³² The safety effect of Child Car Seats is far from clear, see e.g. (Levitt 2008).

³³ (Fyhri et al. 2011).

³⁴ The Governors Highway Safety Association, a US watchdog outfit that looks out for safety on the highways summarizes some of the changes affecting licensure by state. For instance, most states have a three-stage driver's license (Learner, Intermediate, and Full). Full now starts at 17 or 18 years old in many states. The Intermediate stage imposes nighttime driving restrictions (48 states) and passenger restrictions (47 states) in many states. Novice drivers (under 18) are also prohibited from using cell phones or texting while driving.

When both of our parents schlepped us to Sears or Montgomery Wards, we sat in the front seat of the car. If our car was old enough, maybe – just maybe – we wore lap belts because the three-point seatbelt (the shoulder-belt) had yet to hit the American auto market.³¹ Today children sit in the back seat because of the rise of so-called 'child safety seats' and air bags.³² Today's back seat kids have a much diminished independent range,³³ and are more likely to be chauffeured by a parent or school bus to their school.

But we contend there are things, tacit knowledge, one can learn about driving just by riding in the front seat, which today's kids are slower to experience. These include laws of the road, etiquette, and defensive driving. Both of us received our driver's licenses upon turning 16, not a day after. After a few weeks of restricted driving we were on our own. Today it is more complicated for young people to get driver's licenses, and less valuable since they need more supervision. More teenagers are deferring licensure and auto acquisition.³⁴

Boys will be boys. Getting a license is also less valuable since it is harder to get away with driving drunk, the way George W. Bush and Dick Cheney did in their younger years. Driving While Intoxicated (DWI) was as recently as 15 years ago not considered severe enough a crime to keep someone out of the White House. We wish such poor judgment were now. It certainly can affect employment prospects at jobs society takes more seriously.

Ad Age reports:

"In 1978, nearly half of 16-year-olds and three-quarters of 17-year-olds in the US had their driver's licenses, according to Department of Transportation data. By 2008, the most recent year data was available, only 31% of 16-year-olds and 49% of 17-year-olds had licenses, with the decline accelerating rapidly since 1998."³⁵

³⁵ (Neff 2010).

A recent study by the Center for Disease Control finds that “three out of four US high school students aged 16 years drove at least once during the 30 days before the survey.”³⁶

³⁶ (Center for Disease Control 2015).

This number fell from about 85 percent who drove in an average week in 1996.³⁷ Our own analysis finds³⁸ licensure notably lower for the most recent demographic cohorts in the Minneapolis-St. Paul region compared with earlier groups at the same age. Vehicles per household is higher for the youngest demographic, which we attribute to the youngest cohort being more likely to live with their parents than earlier cohorts which left home never to return. Total vehicles per capita (Shown in Figure 1.4) is off the peak in the US.

³⁷ (Shults and Williams 2013).

³⁸ (Levinson et al. 2015).

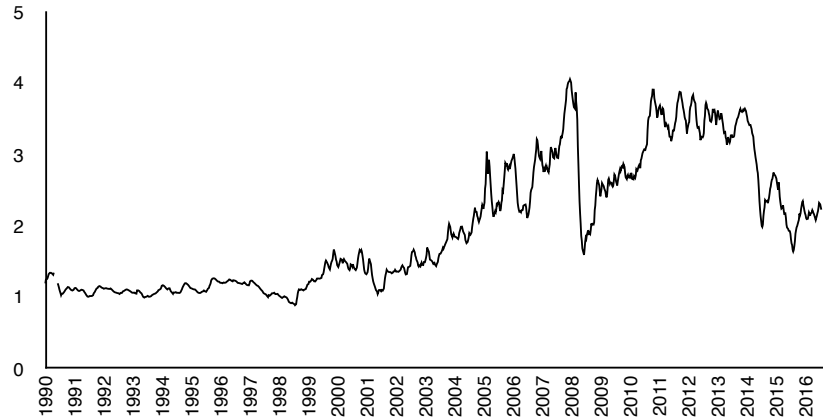
When you go through life as a back-seat passenger rather than a driver or shotgun passenger, we contend your motivation for driving is lower, since you are not modeling driving yourself as you would watching through the front windshield. Thus you may defer licensure. Further, your quality of driving is lower since you lack experience from sitting ‘shotgun’³⁹ and looking out the front instead of side window growing up.

³⁹ Shotgun is the front passenger seat, where presumably, as in a 1930s gangster film, someone carrying a shotgun would sit to shoot out the window, while the driver controlled the vehicle.

These two factors feed on each other, as people like doing what they are good at. Drops in licensure are in part related to less value associated with licenses, and there may be other causes as well, including the factors described elsewhere in this chapter.

3.7 Fuel Prices

Figure 3.10: Weekly average US retail gasoline price (dollars per gallon) 1990-2016. Source: US Energy Information Administration <http://www.eia.gov/petroleum/gasdiesel/>.



Gasoline is a major input into trip-making as most vehicles use Diesel or Internal Combustion Engines. The price of fuel increased sharply in the run-up to the Great Recession, as shown in Figure 3.10 this certainly discouraged car travel. Interestingly, it also reduced car crashes by more than the reduction in distance traveled, which the research team attributed to worse than average drivers (especially the young) being more likely to be priced off the road.⁴⁰

⁴⁰ (Chi et al. 2013a;b).

How much less travel is there because of increases in the price of gasoline? For every 100% increase in the price of gas, there is a 5% decrease in gasoline consumption, which correlates to driving in the short run. In the long run there is also a shift in vehicle fuel economy, and a greater decline fuel consumption.⁴¹

⁴¹ (Hughes et al. 2006).

While the relationship between fuel prices and driving levels is relatively weak in the short run, a larger context invoking the costs of vehicular ownership, costs of maintenance, and ever increasing costs of travel (i.e., parking fees, tolls, the price of gas, in addition to an increased intolerance for traffic congestion itself) has caused increasing populations to consider car ownership in the first place. Though most adults of car-owning age still own a car, more people are deciding otherwise, as shown in Chapter 1. Many households are going from 3 to 2, 2 to 1, or even 1 to 0 motor vehicles.

3.8 Competing Modes

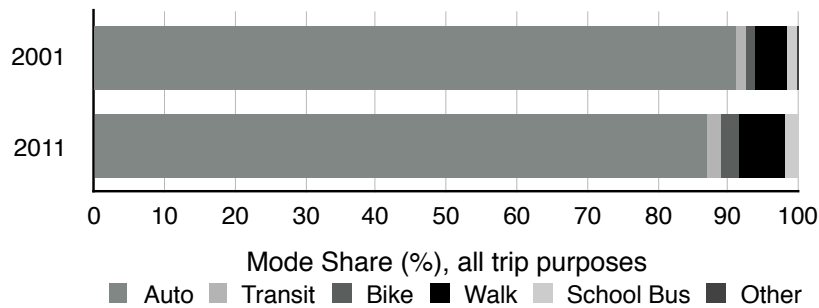


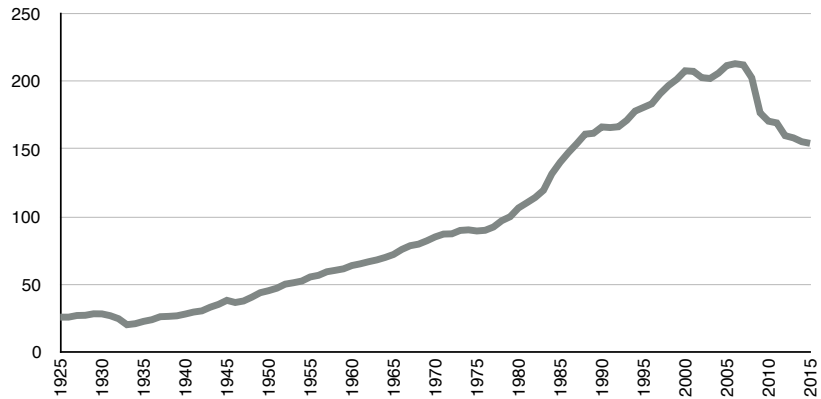
Figure 3.11: Mode shares in Minneapolis - St. Paul region, Summer 2001 vs. Summer 2011. Source: (Levinson et al. 2015).

Finally, an explosion of other mobility options in cities have become more available, attractive and increasingly used. Proportions of trips via carsharing, ride-sourcing and bikesharing are generally still too small to reliably measure. However, walking, cycling, and even transit are holding their own or growing compared to the automobile. Aggregate transit use across the US is up, largely owing to large investments in rail lines; a 20 percent increase in transit use in the last decade (amounting to about 1 percent of all travel) is far less the 10 percent drop in per capita passenger travel by motor vehicles (about 8 percent of all travel). Recapitalizing transit has had marginal effects. Rather, as is the theme of this chapter, the decline in per capita auto use is a death by a thousand cuts rather than one clear perpetrator.

Shares of walking, cycling, school bus, and telecommuting appear to be generally increasing in many cities across the globe. Illustrative data for the Twin Cities is shown in Figure 3.11. Such rise is likely attributed to changing preferences, mostly, and the economy, secondly, as discussed in earlier sections. Increase in school bus travel in the US is likely due to changes in schools (which are bigger and farther apart) and increased movement away from the neighborhood school.

3.9 Occam's Razor

Figure 3.12: Billions of pieces of mail handled annually by US Post Office 1926-2014. Source: (Historian, US Postal Service 2015). US mail volume increased for decades upon decades until the 1990s. And it started to level off in the 1990s (forming an S shape from 1926 to 1999) with the rise of email and the Internet, and then, since the early 2000s has fallen off a cliff (the beginning of a reverse S). Nobody today expects the number of letters delivered to rise in a decade's time. This same pattern could confront the conventional automobile as we know it today.



"Among competing hypotheses, the one with the fewest assumptions should be selected" – William of Occam's Razor.

It is too difficult to say which, if any, of these explanations have the fewest assumptions, thereby satisfying Occam's Razor. Instead, like Agatha Christie's novel, the guilt is spread over many shoulders. As issues evolve over the upcoming years, more characters will be added and the specific role of any one culprit might become more pronounced. For the time being, however, it is safe to say that conventional automobile traffic is suffering a slow death by a thousand cuts. Interestingly, almost none of them can be attributed to conscious public policy aimed at traffic reduction.

Furthermore, charging one culprit is less important than waking up to the reality that *transport operates differently these days*. People seek convenience in their daily routes. They seek not having to pay attention when they drive. They definitely seek not having to drive in traffic. Seek and ye shall receive. Convenience, safety, and inattention are hallmarks of future mobility.

Such anticipation, however, needs to be tempered. All technologies have a lifecycle associated with them – which can be graphed with an 'S-shaped' curve. Things start off, they grow slowly, there's a period of steady, rapid growth and an eventual leveling off. Something new happens and the S-curve begins to move in the other direction as the technology declines.⁴²

⁴² This is discussed in more detail in (Garrison and Levinson 2014).

4

Pace of Change



Figure 4.1: Pace of Change.
Photo by Kevin J. Krizek.

Vehicles might move slow or fast along city streets. More generally, so do technologies. This chapter differentiates technologies by their pace of change: Fast, Medium, Slow. Slow technologies are the most rigid. Decreasing their rigidity has advantages. More importantly, recognizing rigidity helps us understand when various changes might take place.

FAST CHANGE. Matching the prospects of decreased driving with the wonders of technology provides fuel to buoy optimism. Trends are bending around vehicle use, overall travel, and technology. Ray Kurzweil,¹ for instance, observes that technology advances at an accelerating rate, and is deployed more widely more quickly today

¹ (Kurzweil 2005).

² (Dediu 2013).

³ The acceleration of technology is admittedly a contested point, with authors like Tyler Cowan (Cowan 2011), Peter Thiel (Thiel and Masters 2014), and Robert Gordon (Gordon 2016) notably identifying the problem of economic stagnation.

⁴ A kilobyte here is actually 1024 bytes, not 1000, so the conversion is not straight-forward in decimal math as it might appear, moreover while disk drives use metric definitions of kilo (=1000), memory makers use the kilo = 1024 = 2¹⁰.

⁵ As of 2013, 56% of all American adults are smartphone adopters; one-third (35%) have some other kind of cell phone that is not a smartphone, and the remaining 9% of Americans do not own a cell phone at all (Smith 2013a).

than yesterday. Horace Dediu has made a similar point less breathlessly.^{2 3}

If not arriving at a 'technological singularity,' we see accelerating technical progress as fairly obvious; it applies most clearly to the information technology sector, where Moore's and kindred laws show the period of doubling of various technology. David's first personal computer was an Apple II+ with 48 kilobytes (kB) of memory. He spent more than \$100 to upgrade with an extra 16kB. He is typing this book on an iMac with 16 Gigabytes (GB) of memory. 16 Gigabytes is about 350,000 times as large as 48 kilobytes.⁴ This is not linear growth. That is not to say David is 350,000 times as productive with his new computer as his first, but he is more productive. The problem is that just as technology is getting progressively better, the challenges it is asked to address become more challenging.

In recent years, the fastest changing technologies involve computers and information. In general, the short-term forecast of new technologies tends to be overly optimistic about rates of adoption, market size, and its ability to displace business as usual. However, society at-large has swiftly transitioned from pens to keyboards; from keyboards to mice to swiping fingers across screens; and to voice-responsive headsets, phones, remote controls, and free-standing devices interacting with the digital world. Most people now live in an always-on world via smart phones or otherwise.⁵ By using the TouchID sensor on an iPhone accompanied by three light touches with an index finger, it is possible to order a car from a taxi (ride-sharing) service (e.g., Uber, Lyft) to pick you up in a matter of minutes and drive you anywhere. Employing the same gestures, dinner is literally on-tap this evening, delivered fresh. You can now have reliable video chat with friends or family across the world while walking across town.

MEDIUM CHANGE. There are an estimated quarter-billion cars and light trucks (including pickups, minivans, and sport utility vehicles) on the road now in the US. The average car on the road is 11 years old. By comparison, in 1933, in the depths of the Great Depression, the turnover sales rate of the auto fleet was over 14 years. So what are the odds that your next vehicle will last over 20 years?

The private automobile fleet in the US turns over slowly. This frustrates those used to the fast change of Silicon Valley. Cars are idle most of the time, and thus fail to wear out and don't need quick replacement. If instead of 250 million vehicles operating 1 hour a day, suppose society had 125 million vehicles operating 2 hours per day,

or 62.5 million vehicles operating 4 hours per day. Vehicles would be replaced 4 times as often (assuming they wear out with use), and the average age of vehicles on the road would be under 3 years instead of over 11 years. In contrast, David has had 7 (different generations of) cell phones in the past 11 years.⁶

Newer cars have several advantages. They are more fuel efficient, pollute less (both because they use less energy and because they have better pollution control), are safer, have better user interfaces (we hope) and are more in-sync with changes in information technologies. Society wants fewer cars because that requires less space devoted to the storage of cars (parking), and makes driving less likely.

Efficient use of capital, keeping vehicles in motion 24/7, is a hallmark of large, expensive fleets like shipping, airlines, railroads, and to a lesser extent trucks. Furthermore, a single owner of the fleet can achieve larger economies of scale. United Parcel Service controls almost 100,000 vehicles world-wide,⁷ allowing them to innovate in use of alternative fuels. Transforming this mid-speed technology to faster moving is an opportunity that new technologies portend, an opportunity we discuss in Chapter 8.

⁶In contrast, for 43 years of his life, Kevin was without a cell phone. It was not until September 2014, when David reminded Kevin: “how can you expect to be a self-respecting and authoritative voice on the future of urban transport if you don’t own a smartphone?” that one of the last of the Mohicans had fallen.

⁷(Schlangensteen 2014).

SLOW CHANGE. In contrast, roads are among the slowest changing of any technology still in active use. In 2006, David and his family lived in London – a city which formed around a the shape of streets from centuries ago. After the 1666 fire destroyed most of London’s buildings, the city could not change its street grid despite an able plan from Sir Christopher Wren. In 2014 Kevin and his family lived in Bologna (in Northern Italy, just over the Apennines from Florence). The street on which he lived for a year was the *via Emilia*; this exact road was built in 187 BC by the Romans. It was a main trunk road then and still is today. Once laid, roads do not move. They continue to define the urban fabric. Too many institutional arrangements (such as property rights) depend on the old layout of roads. Almost always, new buildings are built where the old structures stood, rather than in the void of empty roads. Similar observations can be seen after San Francisco Earthquake and the bombings of German and Japanese cities in World War II.

The life-span of buildings obviously varies a few years to centuries; commercial structures in the US hover around a half century.⁸ Property rights inevitably change slower than that, thus it is not unreasonable to think that streets are not going anywhere soon. *Yet, there will be opportunities to reconfigure how the roads themselves will be used, which we discuss in Chapter 14.*

⁸(ECPD 2014).

⁹ William Gibson is reported to have first said this in an interview on *Fresh Air*, NPR (1993-08-31)

“The future is already here – it is just not very evenly distributed.” – William Gibson.⁹

“In the future, everyone will live and behave like the futurist does today.” – The Futurist Fallacy.

DYSSYNCHRONY Both Gibson’s uneven distribution and our Futurist Fallacy may hold provided that the futurist is not in fact behaving the way future will turn out. Of course every good futurist will try to behave in a future-oriented way, living at the cutting edge of technology and lifestyle. Many of those technologies however turn out to be techno-evolutionary dead ends and those futuristic lifestyles will be fodder for late-night television. Gibson’s quote resonates well because it comports with our idea of pace of change. Deployment takes time, and some things by their inherent nature are harder to change than others.

¹⁰ Also worth reading on this is the discussion of “Clash of Speeds” in an interview of Alvin Toffler ([Gardels 2016](#)).

Focusing on the auto/highway system, society is confronted with a condition where slow meets fast.¹⁰ Permanent roads are used by fast-moving vehicles whose reaction times will soon be in terms of a fraction of a second controlled by traffic signals whose timings vary by the second. Seemingly immutable roads, when coupled with fast-changing newer information technologies, creates a dissonance. People have come to see things change quickly on the Internet and are frustrated by the pace of change off of it.

Such dissonance provides a window through which to see the forces at work in shaping the future of transport. This slow pace of change is a two-way street. Those seeking rapid change will be frustrated; those seeking to make lasting change will be rewarded.

Part II

Technology

5

Electrification



Figure 5.1: Charging Electric Vehicles. Source: Pixabay.com (CCo license).

In 1900, over one-quarter of the cars produced in the US were electric; however, this amounted to only 1200 vehicles.¹

Electric vehicles (EVs) competed with steam and gasoline for market share. Observers believed each would find niches, a ‘sphere of action’ they would dominate: electrics for the wealthy wives of businessmen and professionals who wanted to travel in town, gasoline for the longer distance trips, and so on. Yet, by 1905, electrics comprised fewer than 10 percent of all vehicle sales. By 1918 Henry Ford’s gasoline-powered Model T was dominating automobile sales.² The rest, was, as they say, history. EV sales, even when growing slightly, comprised a smaller and smaller share of the market.

A somewhat different version of this appeared as “Electric Avenue” in *Foreign Affairs*. (Levinson 2014a).

¹ (Nye 1992; Schiffer 1994).

² Model T’s coming off the assembly line, see (Georgano 1997).

5.1 *Charging Up*

Interest in electric vehicles waned for decades. It wasn't until 1969 that General Motors restarted experiments with hybrids, following on a technological path abandoned soon after Ferdinand Porsche built a hybrid in 1901. Other automakers similarly experimented. The Energy Crisis of the early 1970s revived attention. In 1976, the Electric and Hybrid Vehicle Research Development and Demonstration Act provided modest aid. The Electric Power Research Institute also began support, seeing that EVs could become important for their public utility members.

The production practices of the car, the use of it, and the accompanying provision of land and infrastructure needs prompted considerable consternation for environmentalists including both use of non-renewable raw materials and the large impervious surfaces associated with roads and parking. The primary source of this concern, however, stems from both its intake of refined oil and the tailpipe emissions caused by an ICE. Electric batteries address both.

By the 1990s, the market was getting more ready, with gasoline scarcity, energy independence, and environmental concerns used as rationales. California implemented (but later deferred) policies requiring Zero Emission Vehicles on the road. The unfortunately named GM Impact, designed by Paul MacCready, entered the market with high hopes. Later dubbed the EV₁, it plied the roads of California for a few years before being recalled by GM, as documented in the film *Who Killed the Electric Car?*, which considered oil companies, GM, politicians, and consumers as among the suspects. The main problem that dogged EVs in the first decade of the twentieth century: insufficient range, how far the car could travel on a single charge, had not been solved by the last decade of that century. The second problem: the ability to recharge quickly without wearing out the battery, had not been solved either. The small EVs of the era saw about 70% of their weight made up of nickel lead acid batteries.

In the early 2000s, Hybrid-Electric Vehicles (HEVs) started to become visible (especially the Toyota Prius in California), overcoming the range concerns as electric power would be used on city streets, and the ICE could recharge the battery, at somewhat higher sales price than conventional vehicles. As shown in Figure 5.2, US sales are generally rising, but are still small for Hybrids and Electric Vehicles. Sales outside the US are similarly low.

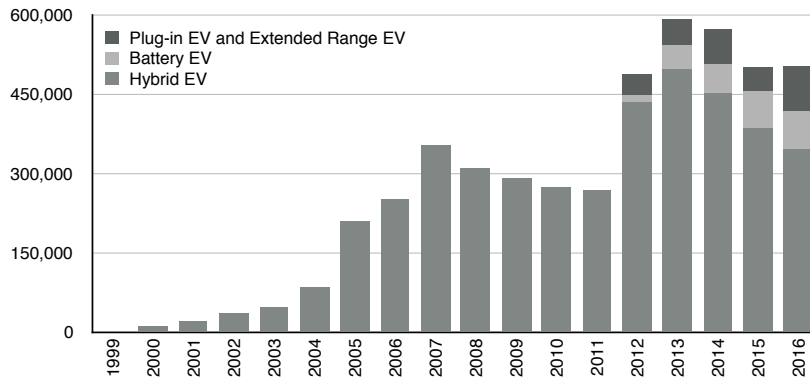


Figure 5.2: US sales of electric vehicles 1999-2016 Source: (Electric Drive Transportation Association 2016).

5.2 Symbolic Energy

In the United States, EVs have become status symbols, a way to wear your concern for the environment, or your technological progressiveness, as a badge. Owners of EVs once painted the word 'Electric' on their cars. With HEVs, the design of the vehicle itself was a slightly more subtle signifier (known to all who matter) that the Prius owner cared more about the environment than you did. As social markers, hybrids also become fodder for the culture wars. Some states gave hybrids, and later plug-in EVs, free access to High-occupancy Vehicle (HOV) lanes, which had been designed for carpools and buses, as a reward for their owner's socially commendable behavior, others disagreed.

Robert Laughlin wrote an essay "The Earth doesn't care if you drive a Hybrid" (later retitled "What the Earth knows" in *American Scholar*:³

³ (Laughlin 2010).

"[The Earth] doesn't notice when you turn down your thermostat and drive a hybrid car. These actions simply spread the pain over a few centuries, the bat of an eyelash as far as the earth is concerned, and leave the end result exactly the same: all the fossil fuel that used to be in the ground is now in the air, and none is left to burn."

Symbolic action may make the actor feel-good, but cannot make a real difference to the environmental problems it purports to address. Laughlin, a physicist thinking geologically and thus longer term than most 'climate scientists,' expresses a belief in the futility of the response to global warming and skepticism about whether its consequences are all that great when compared to all that has happened to the earth before.

5.3 *Take Off*

GM and Chrysler, two of three largest remaining large US automakers were briefly nationalized following the economic shock of 2008. Ford remained private. Federal policies on emissions and fuel efficiency were ratcheted up in this period.

The number of green and technophile status seekers is insufficient to carry the market beyond its current level. Something more substantial, a product that is considered superior by most customers for most purposes, is required. GM re-entered the plug-in EV market in 2011 with the Chevy Volt, while Nissan entered with the Leaf and Honda with the Fit.

To provide a sense of the technology, the Honda Fit has an energy efficiency of 18 kWh per 100 km (lower is better) combined City and Highway, which the EPA scores at 118 Miles per Gallon equivalent (50 km/liter) (higher is better), with an 82 mile (132 km) range. The US government provides \$2500 tax credits for plug-in EVs, and has in the past provided other subsidies for fuel efficient vehicles. Many states and other countries provide additional subsidies.

New companies formed to market high-end EVs. Leading the charge, Tesla, was founded by serial entrepreneur Elon Musk, also famous for SpaceX, Solar City, and PayPal, as well as Hyperloop and The Boring Company, which aims to dig tunnels cheaper. Their continued growth, occasional profits, and increasing sales are paving the way (no pun intended). Tesla's fame is derived in large part from automobile production, but their real advances are as a robust battery manufacturer.

Sales of EVs, shown in Figure 5.2, remain in the thousands, while the US market is about 13 to 14 million cars and light trucks per year.⁴ That has not stopped Musk from claiming most new cars will be EVs within 20 years. Tesla's newest Model 3 obtained over 400,000 pre-orders within two weeks of announcing the car, and more than a year before the first delivery.⁵ Indeed, Battery EVs are following the same trajectory of growth as Hybrid EVs a decade earlier. And while Hybrid growth was quite rapid in its early years, it has significantly slowed in recent years. Market shares for hybrids are well off their 2013 peak, though battery and plug-in electric vehicles are gaining share.

Running a best-fit logarithmic curve through the data, and assuming an eventual market saturation at 100%, yields a 50% market share of new sales in 2023 for EVs and HEVs combined, not too different from Musk's claim about EVs alone. As with any such forecasts, a high dosage of salt is required.

Is 2023 reasonable for a 50% EV+HEV market share for new cars? Note that even if that year holds, it will be some years still before the fleet itself is 50% EV, as the median age of the car on the road is about 11 years now. Unfortunately, extrapolation with such limited

⁴ Estimated Battery plus Plug-in and Extended Range EV sales were at about 0.7 percent market share in 2013, up from 0.0 percent in 2009.

⁵ (Smith 2016).

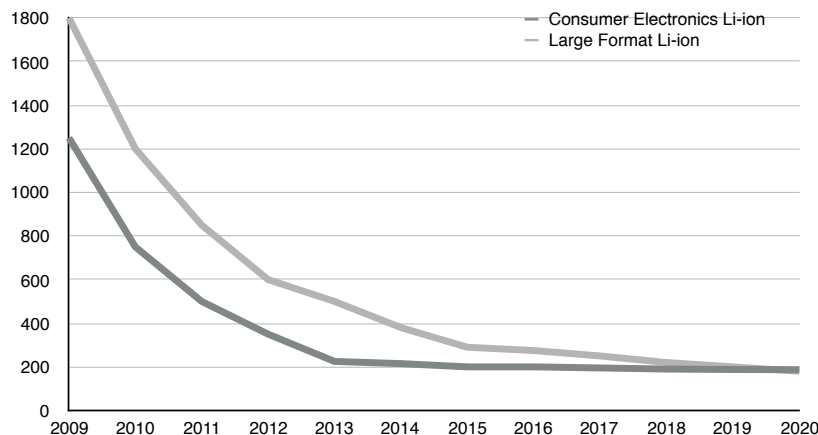


Figure 5.3: Lithium ion battery pricing by cell type 2009-2020 estimated (\$/kWh). Source: (Jaffe 2014).

data is at best dodgy, as there are many factors are play.

In favor of rapid adoption is the potential of a policy-push strategy. The US, or individual states, and other countries may implement cap-and-trade for refineries or carbon taxes.⁶ California, notably, already has a cap-and-trade system which implicitly raises the price of gasoline, to date by a bit more than a dime a gallon.⁷ In such a scenario, battery vehicles will be more popular because the alternative has become more expensive, though the degree of price increases in gasoline affects the popularity of the alternatives, and a dime ain't much.

Similarly, if the price of fuel increases substantially over the long term due to changes in markets (lack of new discoveries, increasing demand in developing countries), that might also tip the market.

Also supporting adoption is the possibility that batteries will eventually be better choices than the ICE from a strict efficiency standpoint (range, and/or cost per distance). But that date is at least a decade away at current rates of improvement in the battery market. Figure 5.3. shows one projection of cost of Lithium Ion batteries. The ICE is not a sitting target. There are still possibilities for non-linear breakthroughs that could produce significant improvements in range and energy density.

Moore's Law, which predicts doubling of computing power every two years or so, does not apply to batteries. However, there are gains in energy density, which has been estimated at doubling every 10 years or so. Over the last six decades, the maximum energy density of rechargeable batteries has increased tenfold.⁸ At this rate, it would be 2030 before the target of 500 Wh/kg will be reached (where range for batteries is comparable to range for gasoline

⁶ There are many equivalent environmental taxes, some of which may be politically easier sales than others.

⁷ At about \$13/tonne CO₂ at the time of this writing. See (Calcarbondash.org 2016).

⁸ Energy density in the past six decades increased from 25 Wh/kg to 210 Wh/kg. As a point of comparison, the Tesla Roadster was at 117 Wh/kg and the GM Volt is at 140 Wh/kg and Leaf at 155 Wh/kg. Tesla is presently reported to be using Panasonic batteries delivering 240 Wh/kg in the Model S. Prototypes by GM claim to be at 400 Wh/kg. (Cobb 2013; Ottaway 2014).

⁹ (Schlachter 2013; Zu and Li 2011).

engines), recognizing the gasoline engine will improve over that time as well.⁹ Not much can beat the energy density of liquid petroleum.

Potential new adopters remain leery of vehicles with unfamiliar maintenance requirements. As EVs become more widespread, and prove themselves, this fear will diminish. Today, California also has a more widespread EV charging network than the rest of the US. Over time, EV charging stations will be more common than gas stations. Gas stations have declined from 300,000 to 140,000 in the US in a decade, and already there are no gas stations left in lower Manhattan, while charging stations are becoming common.¹⁰ There are over 10,000 charging stations in the US, and many EV owners can charge at home.

¹⁰ (Nir 2016).

5.4 *Beyond Batteries*

On-board batteries are only one possible technology for supplying electric cars with energy. Others include ultra-capacitors and fuel cells. In the late 1990s there was excitement about the prospects of hydrogen fuel cells.^{11,12} But while costs have been driven down, fuel cells have yet to be cost-effective comparable with batteries, much less ICEs, and the most optimistic thing we can say is the timeframe of the promoters has been stretched. Like fusion power, fuel cells have been five years away from deployability for more than two decades.

¹¹ (Koppel 1999; Hoffmann 2012).

¹² Some EV advocates saw federal support of fuel cells in the Republican Bush administration as a way to avoid investing in the more promising and near term technology, and thus providing back door support to existing oil interests). See e.g. (Foote 2015).

Another interesting strategy is Dynamic Wireless Power Transfer. Charging coils embedded in the pavement transfer electricity to on-board batteries while the vehicle is in motion. This allows the battery to be much smaller since it is recharged more frequently. The most obvious initial application is for electric buses, which return to fixed points (bus stops) regularly. Over the longer term, one can imagine freeway lanes configured for charging, particularly on intercity highways, to solve much of the range issue. This is a potential source of revenue for highway agencies.

While there are technology trials, this is still speculative, as installation would tend to be expensive, and no agency wants to undertake a widespread installation until there is a fleet ready to use (and pay for it), and few will want to depend on this without a network being in place. However it could ratchet up if a home wireless charging standard for EVs becomes standard, and so EVs already have the technology to be wirelessly recharged. It should be noted that this would flip two of the greatest weaknesses of EVs (range and charging time) into a strength compared with ICEs since

the range would be anywhere with wireless charging, and the 'fill-up' time would be used for something else simultaneously.

Electricity production still has considerable emission costs. Furthermore, the disposal of batteries prompts environmental and ethical issues.¹³ The overall environmental problems, however, are less severe and more easily controlled (as concentrated local point sources are easier and less expensive to manage than distributed mobile sources). Electric vehicles (EVs) powered by electricity generated from natural gas or wind, water, or solar power were recently and robustly shown to have clearly superior air quality quality impacts, surpassing the environmental benefits of almost a dozen other energy sources.¹⁴

¹³ Power plant emissions are far more localized, and much more readily addressed compared with the tailpipe.

¹⁴ (Tessum et al. 2014).

The electric car has been long projected and hoped for due to both environmental and energy reasons, yet the relatively low price of liquid fuel and its advantageous energy density (giving it a longer range than batteries) has deferred widespread adoption. Technologies are finally converging to enable electric vehicles to be competitive with, and eventually surpass, liquid fuels.

5.5 *Range Anxiety*

The EV's range anxiety/charging problem may be solved by fast-charging technology and a comprehensive charging network. Standards here are an issue, as different autos using different incompatible charging devices makes fast charging dependent on the charging station being compatible with your vehicle. Just as fuel pumps have standard size nozzles, chargers need to be standardized. There is no guarantee that there will be a convergence on standards in this market, though the industry is working on this.¹⁵

Battery swap was first proposed in 1900 by L.R. Wallis and was revived with Shai Agassi's company Better Place in the 2000s, which hoped to develop a network of battery exchange centers, before entering bankruptcy. A third attempt at this, by Tesla, was abandoned in 2015. This technology could, but probably won't, help the issue with limited range. The success of the idea depends on economies of scale and standardization of batteries. Unless and until electric batteries use an interchangeable standard, or one firm dominates the industry, there is the risk that the right battery size will not be in-stock. While this is sometimes true of other parts of your car that require service (e.g. tires), tires are not promised to be replaced in 5 or 10 minutes.

¹⁵ The standard for EV charging in North America is SAE J1772. The standards for fast chargers (superchargers) are still more up in the air. The Tesla Supercharger is not compatible with others. (Kane 2013).

With Mobility-as-a-Service (Chapter 8), Pony Express type

services, which swap the vehicle rather than the battery may be possible.

Finally, perhaps the few long trips people actually make will use a mode other than the car, or remain with liquid fuel, if the range problem persists.

5.6 *Electric Transit*

For transit (Chapter 12), much of the network, particularly urban rail (metro, LRT, and streetcar) along with electric trolley bus, is already electrified. Battery powered buses are now being tested and are in operation on some routes – London has ordered 51 and plans another 3300.¹⁶ Fuel cell buses have also been put into operational tests. Other fuels, such as natural gas, as well as diesel/electric hybrids are becoming more common. The same advances in electrification that are expected to affect automobiles will play themselves out in the bus market. Battery powered buses will likely win this competition, as the economies of scale with battery production for automobiles will have significant positive spillovers for buses. New technologies such as in-road wireless chargers, especially located at bus stops, provide the additional promise that batteries need not be too large (or heavy), as the bus can periodically sip electricity from the grid while passengers board and alight.

¹⁶ (Brian 2015).

5.7 *Alternatives to Electrification*

US Federal policy is not engaged in a ‘bet the farm’ strategy of putting all its research eggs in one basket. Instead, it is spreading its money across a variety of technologies, each of which most observers believe are not terribly promising, but each of which has supporters. Battery EV defenders are skeptical of fuel cells, and everyone is skeptical of the benefits of biofuels like ethanol, which though mandated to be blended with fossil fuels, are likely to max out around 5 or 6 percent of total US fuel consumption.¹⁷ Natural gas has its partisans, particularly for trucks, though again shares of total heavy duty fuel use are likely to be no higher than 10 percent of fuel consumption before 2040, and an infrastructure of fueling stations is required. Technologically, all of these probably can work. Which of these has the best business plan and will succeed in an unsubsidized, or at least less subsidized, market remains open. Many small bets are more likely to find a winner than a few large ones. A Manhattan project or Apollo program is not called for in this situation.

¹⁷ More discussion of Biofuels is in Boies (2016) *Electrification and Alternative Fuels* (Chapter 6) of (Levinson et al. 2016).

Assuming continued economic growth, EVs or other non-petroleum based energy sources will eventually be widely adopted. Each energy source may have market niches or ‘spheres of action’ for a temporary period, while the market is in flux and early adopters experiment with an explosion of vehicle forms. In the end, economies of scale dictate one of these technologies will come to dominate for an extended period, but it remains an open question which. While by the late 2010s most people have come to believe the winner will be EVs, there remains the possibility an alternative succeeds.

While one technology may come to dominate, unless prohibited there is likely to be a niche market in use of gasoline engines, just as some people swear by vinyl records. As Kevin Kelly notes in his book *What Technology Wants*, no technology ever is truly abandoned:

“I say there is no species of technology that have ever gone globally extinct on this planet.”¹⁸ ¹⁹

¹⁸ (Kelly 2010).

¹⁹ One imagines a small *back-to-the-well* movement, just as 1960s hippies went back-to-the-land. Only artisanal, locally sourced, organic, no GMO, gluten-free gasoline for the cars of ‘wellheads.’

As with the automobile itself, this is in a sense inevitable, so long as we still want private transport, and as long as the environmental and supply problems with petroleum remain. However the timing of such a change, and whether the new standard is electricity, or fuel cell, or liquified natural gas, or biofuels, or something else, remains unsettled.

5.8 Consequences of Electrification

The advent of electrification has consequences. Since its 1919 debut, the gas tax has come to serve as the main source of road funding at the federal and state levels. But with electrification, this will come to an end. The US, in contrast with many other countries, dedicates motor fuel taxes to pay for transport. We are already beginning to see ‘the problem’ of better of fuel economy in transport funding. The immediate solution is the politically unpopular step of raising gas tax rates. Longer term, something else must be done. To be clear, there is no obvious reason to move from the gas tax as a funding source before it is necessary, the tax is administratively very efficient, and accomplished the basic policy ends of raising funds from drivers roughly in proportion to use, while discouraging gasoline consumption. (There is an obvious reason to move from the gas tax to tolling as a way to allocate roads space, as discussed in Chapter 15.) But change will at some point become necessary as gasoline engines lose significant market share.

The price of electricity is dropping, and will continue to do so as solar and wind gain efficiency. The price of large batteries should

Figure 5.4: Tesla with Autopilot.



²⁰ This is occurring as the network of US gas stations is dropping, from 202,800 in 1994 to 156,065 in 2012. (NACS: The Association for Convenience and Fuel Retailing 2013).

plummet as mass production kicks in. The efficiency of batteries will make slow increases. More importantly, the network of charging stations and the ability to recharge quickly will become standard.²⁰

We will witness the decline of complaints about tailpipe emissions of vehicles, perhaps to be replaced with concern over the visual blight from solar panels and wind turbines. And, transport will be quieter, posing problems for the blind.²¹

²¹ (Fermino 2014; BBC 2014).

6

Automation



Figure 6.1: Autonomous Uber.
Photo by Dllu. (CC4 license)

In the Mojave Desert straddling the Nevada/California border, that is to say, in the middle of nowhere, DARPA¹ hosted the first Grand Challenge on vehicle automation in March 2004. With the potential of \$1 million going to the winner, the objective was for driverless cars to complete a 150 mile (240 km) route. Carnegie-Mellon University's robot vehicle made it the furthest, completing almost 5 percent of the route, but was ultimately not awarded the prize.

A second run of the event in October 2005 saw five vehicles completing the course with Stanford University's team winning with a time of just under 7 hours.² Within 18 months, vehicle automation technology rapidly improved.

Two years later, in November 2007, DARPA established the Urban Challenge on a closed course at a decommissioned Air Force

¹ DARPA stands for Defense Advanced Research Projects Agency; it is a unit of the Department of Defense, as driverless cars have obvious military application.

² Carnegie-Mellon teams took second and third place. The Gray Insurance Company from New Orleans and Oshkosh Trucks also completed the course.

base outside of Los Angeles. The 60 mile (96 km) route resembled an urban obstacle course. In this race, Carnegie-Mellon took first (4 hours) and Stanford was second (4.5 hours). In this event, unlike the previous Grand Challenges, cars had to have more sophisticated and intelligent sensors. Though road quality was better (paved rather than off-road), the course of the Urban Challenge was far more challenging.

Fast forward just a few years and we see that Google hired many of the leaders of the Stanford and Carnegie-Mellon (CMU), including Sebastian Thrun of Stanford and Chris Urmson of CMU, for their own internal secret project, which they announced in 2010.³ These self-driving cars (the project has been spun off by Google's parent company Alphabet into a subsidiary named Waymo) have since traveled over 2 million miles (3.2 million km) autonomously, mostly around the San Francisco Bay Area, but also more recently in Austin, Texas and Kirkland, Washington (Figure 6.3).

Waymo's cars are map-dependent, operating where the roads have been mapped out in detail, so that they can compare what they see with what they expect to see⁴ – a strategy with obvious strengths and weaknesses.

Strengths of using maps include a better understanding of the environment. Weaknesses include that:

- not everywhere is necessarily mapped, there may be “Google deserts,” for instances some places are private property, and
- the world changes, the map cannot be updated instantaneously.

Each AV potentially updates the map (by uploading sensor data) each time it uses a route. The first Google style AV to pass the unmapped or incorrectly mapped area will update the map as it passes, but it will of course need the capability of traveling with unmapped, incompletely mapped, or incorrectly mapped instances. And if it can do that autonomously, does it really need the map to proceed? If it cannot do that autonomously, there remain issues with autonomous to human control interfaces.

In Fall of 2015, the electric vehicle automaker Tesla remotely upgraded its most recent model year cars (about 50,000 vehicles) with ‘Autopilot,’ making them semi-automated (SAE Level 2).⁵ Elon Musk, the CEO of Tesla, said he expects fully autonomous vehicles by 2018.

David took a test ride with a Tesla owner running the vehicle in Autopilot. As countless internet videos attest, Teslas are able to function in hands-off mode some of the time. They use adaptive

³ (Markoff 2010; Guizzo 2011).

⁴ (Madrigal 2012).

⁵ (Hull 2015).

cruise control to follow the vehicle in front at a desired speed constrained by a fixed following distance, and use lane markings to stay in lane. They change lanes automatically at the request of the driver (who must hit the turn signal).

As was true in Fall 2015, and still true in Fall 2017, none of these functions can be safely performed in a Tesla running 'Autopilot' in the absence of driver observation and monitoring. In fact the vehicle requires the driver to periodically return hands to the steering wheel. The vehicles do not yet automatically stop at traffic lights or stop signs, though it is understood that engineers are working on and testing those functionalities. Ambiguities in lane markings (for instance at freeway merges and diverges, or as a result of road construction or restriping) still create difficulties for the vehicle in Autopilot mode.

First person observations (from late 2015) are that vehicles still over-react on curves (following the average of the inside and outside curve, rather than a fixed distance from the inside curve). The give-way game between merging vehicles and an on-road Tesla cannot yet be safely conducted in the absence of driver intervention. Teslas do not presently drive independently via a map from origin to destination the way Waymo's test cars do. There is no obvious linkage between satellite navigation and mapping and the control function. Teslas appear to be map-independent, and controls are through on-vehicle sensors. They are an indicator of a future to come, but which has not yet arrived.

The episodes described above are far from the first attempts at autonomous cars. At Demo '97 Automated Highway Systems were successfully demonstrated.⁶ Cars could travel at high speeds, without driver intervention when closely following each other at 1 meter spacing, on an isolated test track. Vehicle automation has long been envisioned, dating back to the 1930s and the GM Futurama exhibition at the 1939 New York City World's Fair. While a technological success, the Automated Highway Systems programs were a political failure, and the program was cancelled. Lack of a deployment path was the reason for the cancellation. No one would build limited roads for very few specialized cars.

Similarly, no one would buy cars that could only be used on selected lanes. Autonomous vehicles running in mixed traffic solved this chicken and egg problem, since they would be useful without special infrastructure, at the cost of much higher complexity.

However, after a critical mass of autonomous vehicles hits the road, and once all the bugs are worked out, there will be potential gains (closer following, narrower lanes) for them to travel in

⁶ See (Public Roads 1997).

autonomous-only lanes rather than mixed traffic. Existing managed lanes can be dedicated to AVs. Even general purpose lanes can be designated and redesigned to AV-only traffic in order to increase total system throughput. We may get special AV lanes on highways as an interim step before all lanes on all highways are for AVs only, and before non-AV cars are prohibited.

After six decades of technological dormancy, the automakers are responding to the DARPA Urban Challenge. Waymo and others (including Uber) are seriously investing in advances to remove the driver from the loop for vehicle control. For instance, Delphi, an auto parts manufacturer spun-off from General Motors, drove an automated Audi 3,500 miles (5,600 km) cross-country in March of 2015, with hands-off control 99 percent of the time.⁷ In fact, Delphi's forerunner (GM Subsidiary) Delco sponsored a similar trip in 1995 by Carnegie-Mellon scientists, where the computer navigated 98.7% of the time.⁸ Just as in the early days of the automobile, expect more such demonstrations.⁹ But be mindful of the number of times the driver has to take back control.

⁷ (KurzweilAI 2015).

⁸ (Business Week 1995; Spice 2015).

⁹ (Duncan and Burns 2003).

6.1 A Note on Nomenclature

SAE level	Name	Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment					
0	No Automation	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment					
3	Conditional Automation	System	System	Human driver	Some driving modes
4	High Automation	System	System	System	Some driving modes
5	Full Automation	System	System	System	All driving modes

Figure 6.2: Society of Automotive Engineers automation levels.

Today we have cars. In 30 years we will have cars. But in the meantime, some cars will will driven by humans and others not, and there will be terms to distinguish them.

Most people use the terms Autonomous, Automated, Self-Driving, Robotic, and Driverless as interchangeable. Even wikipedia does not differentiate. Yet some people in the field make a point of the differences.

A self-driving car is not as advanced as driverless, in that driverless doesn't have the back-up of a person taking control, and self-driving might. Driverless taxis are not merely self-driving, they pick up passengers and may be personless.¹⁰ In SAE terms, driverless is Level 5, while self-driving is Level 4 or below.

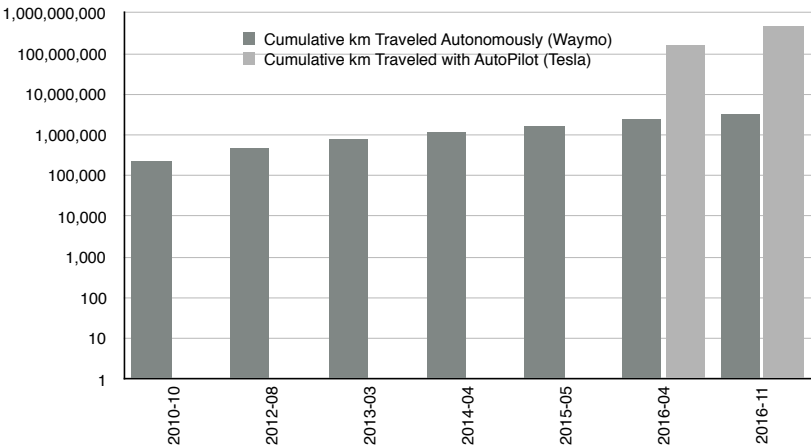
Generally, the difference between automatic (or automated) and autonomous is the degree of human intervention. An automated car does not have the level of intelligence or independence that an autonomous car has. So driverless and autonomous are nearer to synonyms, as are self-driving and automated. A truly autonomous car would decide on destination and route as well as control within the lanes. An automated car would follow orders about destination and route, and may only adopt some lane-keeping or car-following guidance.

Nevertheless, these differences cannot be preserved linguistically, even within the profession, the broad misuse and confusion will drown small differences of meaning. Just as we had horseless carriages, automobiles, and cars, eventually these will be called autos and cars as well. We use the terms interchangeably. Sometimes these terms are incorrectly conflated with 'Connected,' discussed in Chapter 7.

¹⁰ See also *The Economist*, which maintains they are not the same, as self-driving cars are a step further than autonomous vehicles, which lack steering wheels and human control (S.W. 2015). Google uses the term 'self-driving' even for cars which humans can control, thinking the name is softer than 'autonomous.'

6.2 Who's in First?

Figure 6.3: Cumulative km traveled in autonomous mode by Google/Waymo self-driving car and Tesla Autopilot. Source: Google/Waymo/Alphabet and Tesla.



Waymo, a unit of Google's parent Alphabet, is leading by some metrics of AV research, Tesla by others. Waymo is far from profitable. One of the great questions is how long does an organization like Alphabet tolerate losses in an operation before it cuts losses. Many projects are undertaken (ventures are funded) with great promise.

Technological change often happens one bankruptcy at a time, where first movers borrow heavily to invest in new systems with unproven demand. This creates second mover advantages. This is a danger for initial massive investment in self-driving cars in the near future, especially as there doesn't seem to be any demand from the public currently.¹¹

¹¹ (Schoettle and Sivak 2016).

We caution that as Henry Ford never said (but almost certainly felt) "If I had asked people what they wanted, they would have said faster horses."¹²

¹² (Vlaskovits 2011).

In the autonomous vehicle market, suppose someone claims there will be gains in excess of losses, and someone else, with access to a checkbook, believes them. Expected value depends both on the potential and the probability of that potential being realized. In practice both of those are uncertain and dynamic. Today's potential in current market conditions differ from tomorrow's. Today's probabilities also differ from tomorrow's. At what point do you recognize the potential as lower than claimed, and the probability as lower still? When, in Bayesian terms, do you update your priors?

In Waymo's case, the potential of being the first mover is lower because there are now many more people serious about AVs since Google kick-started the latest wave of development of self-driving

cars, following upon the DARPA Urban Challenge. In contrast, the likelihood of success might be higher, since there is now more proof-of-concept.

Unless Waymo imagines itself actually manufacturing cars (probably in a contract facility), one assumes either it hopes to get revenue from

- more eyeballs on Google-ad-powered screens (phones, dashboard, and especially heads-up displays) in a world of AVs,
- cutting a licensing deal with manufacturers, or
- providing mobility services directly as an Uber-type of business.

There is likely value to the unit collectively above and beyond the value of the individual workers (though we have no personal knowledge), so one hopes they keep the team together, under their ownership, or another patient patron.

In some senses Waymo has been overtaken. For services, all major automakers have now partnered with some other company to explore ride-hailing. Toyota and Volkswagen are the latest to announce this (following historically on similar patterns where automakers invested in rental car companies (e.g. Hertz by GM 1925-53 and Ford 1987-2005, Avis by GM 1989 - 96, Dollar-Thrifty by Chrysler 1990-97). Daimler owns car-sharing service company Car2Go and Moovel and is certainly looking at this market. Google rival Apple invested in Chinese ride-hailer Didi. Google has had ownership stakes in Uber, and Alphabet in Lyft.

For autonomous technology, Tesla has cars on the road already. While Tesla Autopilot is not the equivalent of Waymo cars, as it still requires driver attention, it is also a real product accumulating real experience at an accelerating rate, as shown in Figure 6.3, with two orders of magnitude more distance traveled and seemingly fewer incidents per distance traveled (based on press-reports of Google and Tesla crashes).

If the logic of machine learning is right, it will get better and better over time. Autopilot crash experience is better than human driven vehicles.

This is the incrementalist approach, leaving the steering wheel and brakes facing the driver, which counters the more radical Waymo approach of removing (almost) all control from the driver, and trusting the machine completely. The risk has always been the transfer, when the car tells the driver to take over if the driver isn't ready. But if that issue is small compared to the general safety benefit of letting the machine do the steering, accelerating, and braking, it is a risk worth taking.

So will Waymo ultimately close its unit and set its code and data free, let it wither away as staff start up spinoffs like Otto, (since purchased by Uber) or sell it outright to a manufacturer if they choose not to pursue it with gusto? Or, perhaps the rush to dominate the initial market for AVs will lead to a unsustainable bubble that hits everybody's valuation (not just Alphabet's). The market will survive if it does, but there is surely value to the team as a collective.

As of 2017, Waymo insists it will go ahead with public deployment of driverless taxis.

as needed. Subsequently they can pick them up at origins. This requires reconfiguration of drop-off and pick-up areas to avoid large queues. Parking stalls can be narrower and parking decks shorter if people are not required to use them. Cars can be packed more tightly in such parking facilities. Further those facilities will be farther from the high value real estate locations. Parking is further discussed in Section 13.1.

¹³ There is an assumption that lanes and roads are properly maintained. Knowledge about maintenance problems will be conveyed much more rapidly to road operators with driverless vehicles with automated sensors which are connected to the infrastructure provider. Because better lane-keeping can reduce lanes width, it should reduce total maintenance costs.

CAPACITY. Because they are safer, autonomous vehicles can follow other each other at reduced distances.¹³ Lateral distances can be closer and therefore lanes can be narrower. Because they are safer and more precise and more predictable, autonomous vehicles can stay within much narrower lanes with greater accuracy.

If skinny cars emerge, designed for one-passenger, or several passengers in tandem, enhanced by the stability provided by automation, lanes can be narrower still, or be shared with two such cars.

Thus, capacity at bottlenecks should increase, both in throughput per lane and the number of lanes per unit road width. These cars still need to go somewhere, so auto-mobility still requires some capacity on city streets as well as freeways, but ubiquitous adoption of autonomous vehicles would save space on parking and lane width.

SHORTER PATHS. Currently most drivers do not take the shortest path (though we don't really know why that is so, we have speculations). If we take humans out of the navigation decision, cars will be more likely to find the shortest path. This may not be system optimal (which would save a few percent of total travel compared with user optimal travel),¹⁴ but will be a significant improvement over current routing decisions. Not only should we not let people drive, we shouldn't let them route themselves if we want an efficient system.

¹⁴ See Chapter on 'Price of Anarchy' in *Elements of Access* (Levinson et al. 2018).

CARS WITHOUT PEOPLE. Autonomous cars can drive without people at all. They can be used for pickup and delivery, in addition to the dead-heading from drop-off to parking, or from drop-off of one passenger to pick-up of another, or for recharging or refueling. All of this can increase total travel on the road.

MOBILITY FOR THE IMMOBILE. Automated cars will enhance mobility for children and people with disabilities. Parents, friends, and siblings need not shuttle children around; the vehicle can do

that by itself (assuming increasingly protective parents would allow such). The child is securely identified with camera and biometrics, and parents can even monitor their child with an in-vehicle video camera – yielding an environment far more secure than the school buses and carpools children currently ride. There likely will remain debate about how old a child must be before she is placed alone in an autonomous cars, but the consensus is likely to be, if they are in kindergarten, they can ride alone, as with school buses. This is a similar argument with ridesharing services today that offer rides, but that is, to date, a small phenomenon.

Human travel will be much more point-to-point, with far fewer pick-up and drop-off passenger trips required, as those can be off-loaded to the vehicle without a driver. Deadheading autonomous vehicles, driving around without a passenger to pick up their next family member may become common, though logistics and shared vehicles can minimize the amount of this.

NOISE. Many of the sounds of the city are sounds of transport. Engines whirring, car brakes screeching, horns honking, sirens blaring. All of these will become sounds of the past. Electric vehicles are much quieter (so much so that blind persons are concerned), AVs will need fewer braking and acceleration maneuvers, and AVs need not honk in general, as communication between automated and connected vehicles can be silent. Sirens themselves will also be a thing of the past as cars will be able to identify emergency vehicles without the sounds.

RATIONALITY. Autonomous vehicles are coming. Someday soon drivers will pay even less attention to the road in front of them than they normally do. Today, vehicle control is largely an emotional task. In traffic engineering, one of our many abbreviations is PIET:

- Perception – driver sees object
- Identification – driver identifies object (understands stimulus)
- Emotion – driver selects action
- Reaction (Volition) – driver executes action

But this is all very fast, not contemplative, operating in what Nobel Prize winner Daniel Kahneman calls System 1 rather than System 2 in his book *Thinking Fast and Slow*.¹⁵ In short, if we start to think intellectually about whether to apply the brakes, we are already dead. Perhaps one of the causes of road rage is the

¹⁵ (Kahneman 2011).

continued operation within this emotional rather than rational brain for extended periods.

With autonomous vehicles, an hour or two a day for the average driver will be taken out of this high-risk emotional decision context. They will be placed into a more relaxed, less stressful mode, where the most difficult decision will be whether to listen to Pandora or Spotify. In short, the car trip of the future will be more like an office or home than then the uncertain dangers of the open road.

As admirers of *Star Trek's* Mr. Spock, moving towards a more considered, this less emotional world of the future is a good thing, something humans have been doing for millennia as we evolve from the apes.

As we take out what is often the most stressful element of the day, will we 'stress-compensate,' just as we risk-compensate now, and find some other activity to make needlessly emotional? Or will we take our gains in a more civilized society?

COSTS. The capital costs for autonomous vehicles are likely to be higher than traditional cars, at least at first, until driver-facing technologies (like the steering wheel, brake and accelerator pedals, and so on) can be removed for cost savings, as the sensors and computers add some cost compared to existing systems. Those additional costs decline over time, as learning curves, paying off R&D, and mass production all lower expenses.

In contrast, fuel costs should be lower, as autonomous vehicles are likely to be more efficient, both due to less congestion and more optimized driving styles ranging from smoother acceleration to various hypermiling techniques like drafting to reduce drag.

Labor is a significant share of costs in transport, for vehicles such as taxis, buses, and trucks, which today require a driver. With automation, that labor cost vanishes. We imagine a transitional phase where remote control drivers in a traffic center simultaneously monitor and manage multiple vehicles for situations when autonomous vehicles are not fully trusted. We expect those operators to be bored. The elimination of labor cost benefits taxis, buses, and trucks which had held higher costs relative to their competitors like driving alone and trains.

Delivery services with online purchasing will become even more cost-competitive compared to traditional retail. Transit will either be more cost effective than it is now, or be able to offer lower fares, or some combination of the two.

RIGHT-OF-WAY RETROFIT. To accommodate specialized low speed

neighborhood or campus vehicles, most places will require retrofits to enable a connected network of low-speed routes. Retrofitting cities for transport has a long history as cities and transport technologies co-evolve. Cities, which had originally emerged with human and animal powered transport, were retrofitted first for streetcars, and then for the automobile, and in some larger cities for subways. We have also redesigned our taller buildings for escalators and elevators.

Some places where retrofits might be required and feasible include cities laid out and built before the automobile. Much of the street grid can be retrofitted ('calmed') to disallow high-speed traffic. Similarly, retrofits are technically feasible anywhere there is space to install a slow network in parallel with the existing fast network, for instance, with barrier separated lanes on wider suburban roads.

Vehicle diversity applies not only to a larger variety of motorized vehicles of various sizes, but also to a greater variety of transport using the existing streets, which today are highly segregated with cars (both moving and parked) dominating the street and pedestrians the sidewalk. Slow speed, light weight vehicles make 'shared spaces', which don't differentiate between the road and the sidewalk, much more palatable. See Chapter 13.3 for a further discussion of adaptation.

ROADSPACE REALLOCATION. It follows that if transport systems require reduced lane width and have adequate capacity, transport agencies can reduce paved area and still see higher throughput. Today, most roadspace is not used most of the time, but road agencies cannot just roll it up when it is not being used.

However, on freeways the space can be deployed more dynamically to increase either safety (by increasing spacing) or capacity (by reducing spacing), simultaneously adjusting speed and spacing accordingly. Dynamically reversible lanes are possible once humans are out of the loop.

On local streets, roadspace no longer required for motor vehicle movement can be reallocated to other uses (pedestrians, bicyclists, transit, parks and so on), discussed in Chapter 14 about reuse of roadspace. But for purposes of reliability and safety, bikes, bus-rapid transit, and the newly emerging micro-transit benefit from priority lanes, as discussed in Chapter 12.

NOMADISM. For a select few, driverless vehicles may bring back the recreational vehicle, as some choose the fully nomadic lifestyle, spending much if not most of their lives in motion, especially with

low energy costs.

OWNERSHIP. Ownership of autonomous vehicles is a looming question. Will people with regular everyday trips find it cheaper to rent than own? The cost of ownership may turn out to be cheaper than the cost of rental in many if not most US markets (outside central cities). Personally owned cars are not dead-heading everywhere for passengers, lowering energy and operational costs and wear and tear. Owners have more motivation to care for their own car (in subtle, non-detectable ways) than for a rental, so the car may last longer.

While most roads are public; most cars are private and individually owned. Most transit also is public, though services are sometimes performed under contract by private firms. Private roads are emerging, but their use is impossible without public approval and assistance. New forms of ownership and payment will inevitably be a dynamic evolution.

Customers would need to pay for services of any type (either as a subscription or a per-use basis). Advertising could offset – though not entirely cover – some costs. It is conceivable that stores might subsidize transport, as might employers, as benefits for the customers or staff (as they do today with parking). This is discussed further in Chapter 8.

ACTIVITY IN MOTION. One of the advantages of commuter trains over long distance driving is the ability to do something else while in motion. There are a variety of activities that new travelers can undertake. Our colleague Yingling Fan in a recent paper summarizes a number of these activities in the WordCloud shown in Figure 6.4. Reading, talking, and watching are dominant categories. Eating and personal care are likely rising categories in people's own AVs. With new heads-up displays (HUD) in vehicles we imagine new forms of information and entertainment (and advertising) designed for the windshield, projected on glass, but able to be seen through as well. Travelers in their own, customized, space without concern for the navigation task will not only be more productive (have higher utility than) drivers who need to pay attention, but also train passengers, or those who use Mobility-as-a-Service, who don't own their mobile space, as illustrated in Figure 6.7. This will further increase people's willingness to travel.

STATUS. Just as owning a car was once a class signifier in the US, and remains so elsewhere in the world, and as owning a particular

model of car (like a Prius or a BMW) persists as a signifier, we can expect that during the transition period owning an autonomous car will be a class-signifier. It indicates at once that you are wealthy enough to own a new car, and technologically sophisticated enough to trust your life to it. While eventually we expect this to be uniform, early adopters will have very different economic and social characteristics from the population at large. During the long transition, those who cannot afford such cars may come to be vilified as the cause of crashes.

—

While people, animals, weather, larger cargo needs, and so on are still potential confounding factors, autonomous vehicles interacting with only autonomous vehicles should be much easier to design and manage than autonomous vehicles in mixed traffic.

Chapter 8 considers how ride-hailing services such as Lyft and Uber compete with taxis. But with their added labor, such services are too expensive for most people for frequent mobility.

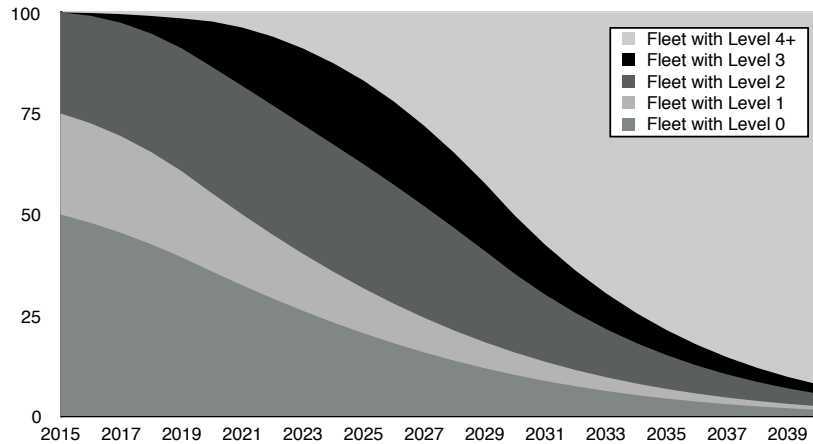
Mobility-as-a-Service currently exists to some extent with the current carsharing companies (Car2go, Zipcar, etc.) which compete with rental cars. But again the cost is too high for most people to use on a daily basis (as Cloud Commuting) for a primary mode of transportation, and unless you live in a place with many other users, the distance to the vehicle may be high. However, with autonomous vehicles, the cost of the driver can be skipped, the car can come to you (just like Enterprise, the American rental car company).

Adam Jonas, Director and Leader of Global Auto Research Team at Morgan Stanley, has a relatively simple idea that he claims will consume his remaining career. As redrawn in Figure 6.6, he offers two intersecting axes to, in part, foretell the future of the auto industry. One axis traverses between ‘human driver’ and ‘autonomous’; the other indicates if the assets (the car) is owned or shared. He believes we are moving from the lower left (human driven, privately owned) to the upper right (autonomous and shared).

In contrast, autonomous vehicle total costs will be significantly lower, making it feasible that larger numbers of people replace their personal car (which is parked 23 out of 24 hours) with one that comes on-demand.

6.4 When: Timeline

Figure 6.5: US vehicle fleet by SAE automation level. Author estimate.



Cumulatively, the driverless distances that have been ‘driven’ are rising every minute.

The time to perfection is far from clear, but one day, soon-ish, you will awake, give a voice command to a car, and never again touch a steering wheel, gears, accelerator, or brakes (which won’t be available for your use anyway) – and so will everyone else. You will step into your car, tell it where to go, and not think about traffic. The window in front of you will be a heads-up display giving you information and entertainment, while allowing you to see the road coming up.

Today, many of the necessary features include lane-keeping, adaptive cruise control, and automated braking technologies are already standard on high-end cars, as is automated parking assistance. Aside from the Cadillac Super-Cruise in freeway travel, none of the automakers advises hands-off driving at this point.

In the meantime, the industry relies on incremental thresholds for what ‘automation’ really means. The Society of Automotive Engineers (SAE) has a series of levels describing degree of autonomy (from Level 0 - ‘no automation’ to Level 5 ‘full automation’), shown in Table 6.2.¹⁶

The Cadillac SuperCruise, which can be described as somewhere between SAE Level 2 ‘partial automation’ and Level 3 ‘conditional automation’ is now being advertised for sale (its actual use in automated mode will be on the relatively controlled environment of the freeway). The Tesla Autopilot, with similar capabilities, is already available.

To give a rough timeline, we anticipate Level 3 (conditional

¹⁶ (SAE International 2014).

automation) autonomous vehicles by 2020; then Level 4 to be available in 2025. Level 4 might be required in new US cars by 2030 and in all US cars by 2040. Our best estimate of the the deployment curves are shown in Figure 6.5.¹⁷

We expect share of travel distance driven autonomously will initially trail the number of vehicles with autonomous capability, as not all AVs will be used in automated mode on all trips, or for the entirety of each trip. Eventually it will lead, as newer and more capable AVs are used more frequently than non-AV vehicles.

Thus we anticipate that automated vehicles will go from their current status of essentially 0% market share to an end state of 100% of all new car sales (i.e. automated capability will be a requirement of new car purchases) by 2030. Furthermore, older human-driven vehicles will be phased out except for special purposes (car shows, races, parades) during the 2030s. Self-driving cars in specific contexts (e.g. freeways or isolated campuses) are expected enter the market before 2020. In other words, human drivers will eventually (around 2040) be prohibited on public roads most of the time, just as horses no longer gallop down our streets.

Consumer acceptance remains an unknown, and depends on the quality of the product being offered. Which companies wind up bringing AVs to market successfully is also an unknown, it may include a mix of existing and new players in the field.

Automated vehicles are probably already legal in most US states (New York requires hands on the wheel),¹⁸ so the burden of proof is on those who want to slow them down. Several states already allow testing of fully autonomous vehicles on public roads, and eventually all will.¹⁹

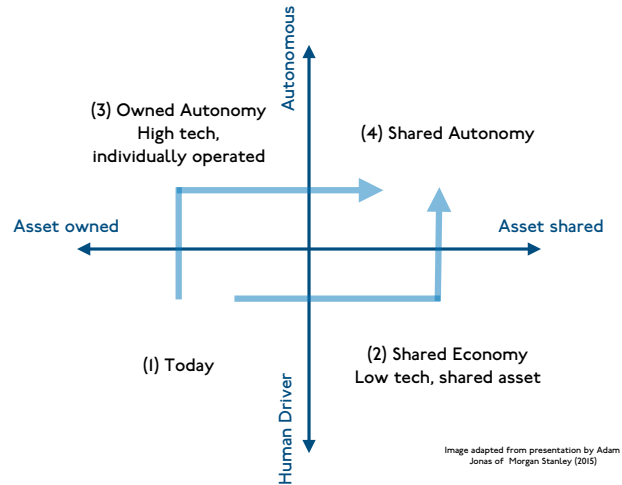
¹⁷ Details in (Levinson et al. 2016).

¹⁸ (Smith 2012; 2013b).

¹⁹ As of 2017 Nevada, Florida, California, Michigan, Virginia, and the District of Columbia, passed legislation enabling testing of fully autonomous vehicles on public roads.

6.5 Where: Environments

Figure 6.6: Future of the auto industry, as seen by Adam Jonas.



The Cadillac SuperCruise's 2017 entry into the 'semi-automated' vehicle market implies the first commercial market for autonomous vehicles would be the relatively controlled environment of the freeway.²⁰

²⁰ (Nunez 2014).

However, entry into the relatively controlled environment of low-speed places makes sense as well. These are two different types of vehicles: high speed freeway versus low speed neighborhood. While they may converge, this is no guarantee and perhaps today's converged multi-purpose vehicle will instead diverge. There has long been discussion of Neighborhood Electric Vehicles, ranging from golf carts to something larger, which are in use in some communities, particularly southwestern US retirement complexes. In Sun City, Arizona, for instance, people use the golf cart not just for golfing, but for going to the clubhouse or local stores (usually as the household's second or third car, but occasionally as the primary vehicle). Such a phenomena exists because local streets are controlled by low speed limits, and there are special paths where golf carts are permitted and other vehicles aren't. Campuses, retirement communities, neighborhoods in some master planned communities, and true parkways are almost ideal for these types of 'driverless carts'²¹ because these places don't have heavy traffic and discourage high speeds.

²¹ We heard the term attributed to Bryant Walker Smith.

6.6 *Thought Experiment – Autonomy Island*

“Look boss, Ze Car, Ze Car.”

“My dear guests, I am Mr. Roarke, your host. Welcome to Autonomy Island. Yes, here on Autonomy Island, all of the cars are autonomous. Your adventure will be to ride and drive and walk and bike in a place without fear of a human running you over.”

An automaker (or collective of automakers, or government, or Google) could buy all the cars on an island (and perhaps rent the government), replace them with new autonomous vehicles, and see what happens . . . to safety, to travel behavior, etc.

This is the kind of real-world laboratory experiment that would be highly useful to understand the implications, the unintended side effects, the bugs and so on of robotic cars.²²

The US Virgin Islands collectively have between 10 and 20 auto fatalities annually. At an official USDOT value of statistical life of \$9.1 million, that is at least \$91M per year. In 11 years, the experiment would pay for itself if in fact it eliminates fatal crashes the way autonomous vehicles are expected to, leave aside any other potential benefits.

The advantages of an island are that it is a closed system, it can be fully mapped, and no one can drive on or off. A real island with real people would demonstrate how these interactions occur in use.

²² For instance, take the US Virgin Islands. St. Croix has a population of about 50,000 people. If it follows general US patterns, it has about 33,000 light vehicles. For about \$1B [Less than the cost of a single NFL stadium] all of the cars could be replaced with autonomous vehicles at about \$30,000 each.

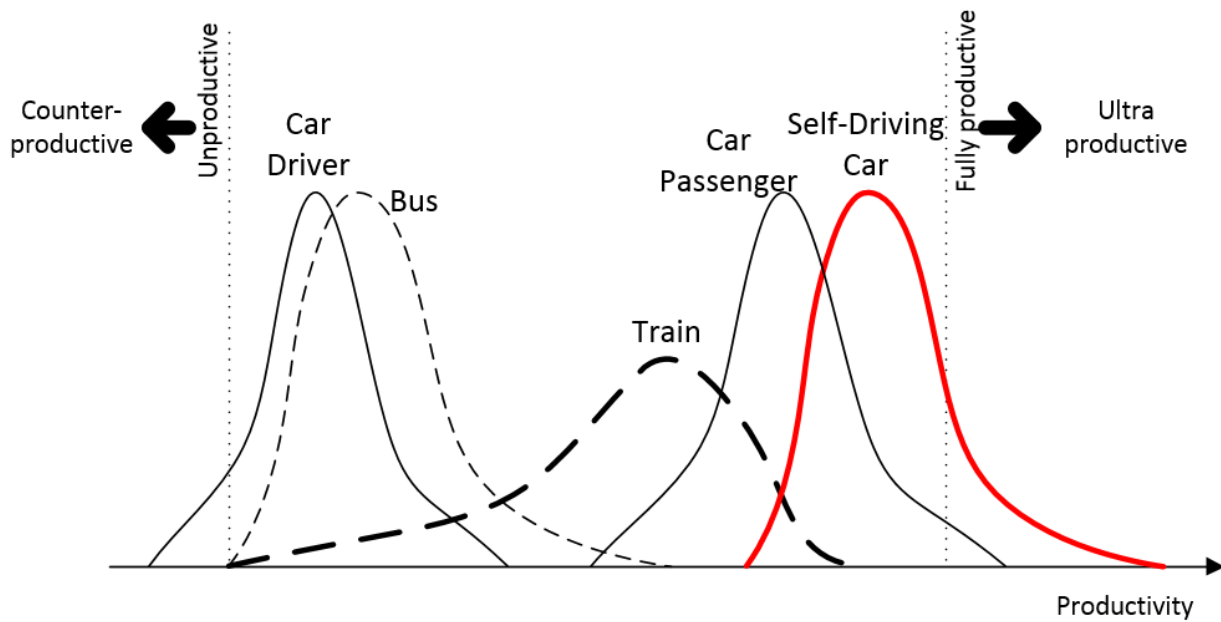


Figure 6.7: Illustrative frequency distribution of 'utility' of travel time by mode. Source: Fan in (Levinson et al. 2016) adapted from (Lyons and Urry 2005).

7

Connectivity



Figure 7.1: Demo '97 National Automated Highway Systems Consortium

Some discussions equate autonomous vehicle technology, described in Chapter 6, with 'connected vehicle' technology. Recently we have to come to hear the phrase 'Connected and Autonomous Vehicles.'

For instance, a UK organization writes:

"Connected and autonomous vehicles incorporate a range of different technologies, facilitating the safe, efficient movement of people and goods.

Increased connectivity allows vehicles to communicate with their surrounding environment. This provides valuable information to the driver about road, traffic and weather conditions. Vehicles with increasing levels of automation will use information from on-board sensors and systems to understand their global position and local environment. This enables them to operate with little or no human input (be driverless) for some, or all, of the journey." (Centre for Connected and Autonomous Vehicles 2015).

To the educated listener, the expression 'connected and

autonomous' may sound oxymoronic, because in many ways, it is. Attaching the governmental word 'connected' to the more Silicon Valley 'autonomous' is a type of whitewashing. Autonomy is about independence, connectedness is about interdependence. History reminds that all of today's networked technologies began as isolated and unconnected instances. Personal computers (minicomputers, mainframes) predated the Internet (Arpanet, etc.). Books, magazines, and newspapers predated the World Wide Web. Motors and generators predated the electric grid. Short, independent, often differently-gauged railroads predated national and international rail networks. Cisterns and septic systems predated water and wastewater pipelines. Crystals and single-celled organisms predated the web of life. It is the natural order of things.

To be clear, an autonomous vehicle needs to be able to make real-time decisions independent of any explicit communication with other vehicles.

A connected vehicle gets and provides information to infrastructure (Vehicle to Infrastructure (V2I)) and other vehicles (V2V) with Mobile *Ad Hoc* Networks. Proponents argue that if connected vehicles were widely deployed, it would not only improve safety for those in the vehicle, it would improve the safety and environment for pedestrians, bicyclists, and other drivers.

Connected vehicles should enable vehicles to anticipate better and negotiate with each other for use of a particular bit of road space at a discrete point in time. Both autonomous and connected vehicles are coming. It is important to recognize that cars may be autonomous but not connected or connected but not autonomous, or both (or as today, neither).

7.1 *Types of Connectivity*

There are a variety of different types of things that fall under the family of 'Connectivity', this chapter lists a few.

CAR RADIOS. The first in-car communication was probably the in-car radio, developed in 1930 by the Galvin brothers, who named it 'Motorola', a riff on the popular RCA 'Radiolas' of the 1920s. This is certainly not what is typically meant by connected vehicles. The first traffic report is unrecorded,¹ but provided traveler information to the driver of the car. Radio traffic reports will soon be consigned to the "Remember When" bin. Emergency vehicles have long had two-way radios, well before the more widespread deployment of the car-phone in the 1990s.

¹ According to Eric Fischer "In San Francisco Chronicle radio schedule listings, a radio traffic report doesn't show up until 5:40 PM, May 26, 1958."

VEHICLE CONDITION. Since General Motors deployed OnStar in 1996, there has been communication between vehicles and a central control about the condition or state of the vehicle. This is especially useful if there is a collision, but can also be of use for personal navigation or vehicle breakdowns.

ELECTRONIC TOLL COLLECTION. The ability to charge vehicles a toll using radio waves reduces the need for vehicles to stop, and is a primitive version of vehicle to infrastructure interaction.

IN-VEHICLE INTERNET. A ‘connected car’ sometimes refers to a vehicle with it’s own Wi-Fi network, connected via cell-phone networks to the internet. This allows people (hopefully passengers, not drivers) to surf the web rather than staring out the window.

TRAFFIC SPEED INFORMATION. The provision of real-time traffic information to drivers, and their traffic information like speeds back to the system can be considered a form of connectivity. Waze is an early version of this, but when you use Google Maps or Apple Maps on your iPhone or TomTom in your car, your GPS location is fed back, and if you are in motion, a speed is derived, along with a timestamp. This is turned into traffic information which is aggregated and packaged for consumer use. More complex reports, like text based data from Waze or even Twitter, are additional less systematic examples. If there is enough data, that can be weighted appropriately, these kinds of data might be sufficiently accurate to provide useful travel speeds where there are no inductive loop detectors. It might even generate traffic conditions or flow data, if the share of vehicles acting as probes at a given time is somehow estimated.²

² (Levinson 2002).

UPGRADING VEHICLE SOFTWARE. Using an over-the-air update, Tesla increased the battery capacity of vehicles in the wake of Hurricane Irma.³ Normally owners would have to pay extra to access the added battery capacity, which was software-limited. Tesla routinely upgrades software remotely.

³ (Tsu 2017).

ROAD CONDITION INFORMATION. One example that is trotted out for the value of connected vehicles is the ice patch. A vehicle driving a road at too high a speed for conditions (because if it weren’t too fast for conditions, the ice patch would not matter) detects an ice patch, hopefully doesn’t crash, and relays that information using some V2I protocol back to a traffic management center, which then relays it to

all other vehicles traveling that section subsequently. This seems fine enough. It would of course be better for the first car to have detected the ice patch before driving on it at too high a speed, and decelerate to an appropriate speed. But what harm can come from this? Very little. More information, presuming it is accurate, is usually better than less. Yet this example is rare. Usually roads are either covered in snow and ice or clear of frozen precipitation. In Minnesota, prior to global warming, the first condition was standard. This is a nice-to-have feature and may reduce some number of crashes per year.

INFRASTRUCTURE SIGNS, SIGNALS, AND MARKINGS. Connected infrastructure could advise the vehicle about controls, as for instance in Figure 7.2. Instead of relying on the vehicle's cameras (or the driver's eyes) to read signs and signals, or digital maps to know of their existence, the intersection would broadcast its state to the vehicle. This could be an improvement, but unless all intersections are so instrumented (a tall order in a big country with many levels of government), it cannot be relied on. An uninstrumented intersection does not broadcast that it is uninstrumented. Instead, the vehicle or driver must know that.

TRAFFIC SIGNAL TIMING. Vehicles broadcast their position to traffic signals, and the traffic signals adjust their timing in response to this information. This does not help pedestrians much.

REAL-TIME PLATOONING. Vehicles can follow other other vehicles, followers receiving communication from the leader of the platoon of accelerating and braking manoeuvres, and synchronize their behavior with a minimum of lag. With this information, cars can presumably follow at closer distances (1 meter following was tested in the 1990s), and thereby increase road capacity and reduce energy consumption.

REAL-TIME NEGOTIATED CONTROL. What most people envision by the term 'connected vehicles,' is the 4-way intersection where no one has to stop. This is far more dangerous.

7.2 *Real-time Negotiated Control Requires Autonomy*

In 2002, David, with a student, Xi Zou, wrote a (sadly unfunded) proposal (and this was hardly an original idea, it was in the air) [Abridged]:

By integrating intelligent agents and Mobile Ad-hoc Networks

(MANETs), the management of low-volume intersections can be devolved to vehicles, without requiring conventional traffic signals, or forcing extended stops at red lights. Advanced techniques such as digital maps, GPS, in-vehicle computers, and mobile wideband communications provide cornerstones of this new framework. Intelligent agents implanted in the vehicle represent the aims of drivers and management. The intelligent agents embedded in vehicles know the vehicle's destination, and like adaptive cruise control, adjust the vehicle's speed up or down. These agents continuously announce their id, position, speed, and acceleration to inform other equipped vehicles over a Mobile Ad-Hoc Network. (While radar and GPS can be used by one vehicle to determine another vehicle's position and speed when it is in line-of-sight, it is insufficiently accurate to determine acceleration, or other attributes when the vehicle is obscured). Based on the position/speed/acceleration of other vehicles, a vehicle proceeds through the intersection at its current speed, slows down, or speeds up to avoid a collision. A consistent protocol used by all vehicles (based on each vehicle's position, speed, and acceleration) determines which vehicle passes through the intersection conflict point first, both avoiding collisions and ensuring safety. Thus intersection management becomes a decentralized operation of a community of agents that might be part of a future mobile society.

In intersection management, the number of accidents and total travel time of traffic can be reduced if drivers/vehicles are aware of the states of other vehicles near the intersection. Current technologies enable vehicles to be aware of their own real-time states such as position, speed, and acceleration, and to communicate with other entities (vehicles or management center). Furthermore, vehicles near an intersection can acquaint themselves with the overall and detailed information about other vehicles. They might evade each other efficiently, avoiding potential collisions. Unlike conventional signal control, we propose microscopic control in which the behavior of each vehicle is adjusted individually. Instead of using stop-or-go control, more flexible passing manoeuvres can be used to increase the capacity in every approach and reduce average travel delay.

In short, Vehicle A approaches from the west, Vehicle B from the north. They will both hit the intersection conflict point at approximately the same time if neither changes speed or trajectory. The traditional rule for this is a stop sign (or signal), either 2-way or 4-way, which delays at least one vehicle needlessly. With V2V (or V2I) communication, some protocol is established whereby one vehicle decelerates relative to the other, and they miss each other by a fraction of a second, traveling almost full speed. There is no delay, no needless braking, no collision, and best yet, for purposes of greenwashing, the environmental impact is lowered because we somehow still all drive gasoline powered vehicles in this imagined future.

Certainly there are possibilities that both autonomous cars accelerate or both decelerate. This could be due to GPS location measurement error (each thinks it reaches first (or second)). In this case a second tie-breaker might be required. For instance, the easternmost car always wins. Both cars should be able to detect with sufficient accuracy which car is easternmost (in this case, the southbound car). So then the eastbound car decelerates, and the southbound car maintains speed or accelerates. Hopefully there is harmony, both cars adjust speeds accordingly as conflict is avoided. No explicit communication was required.

One can imagine other, better tiebreakers, or the need for third tiebreakers (the intersection is X-shaped rather than +-shaped, so they both think they are easternmost), but this can be mapped out. In fact it only requires one vehicle to be autonomous. If after, say, three rounds of chicken (both vehicles increasingly accelerating to the intersection) which is ascertained in less than a second, then the AV decelerates hard to avoid a conflict.

You don't have to like the conceptual algorithm here to believe that such algorithms are possible.

Could this last case be done with autonomous vehicles? It can only be done safely with autonomous vehicles.

You cannot safely rely on the other vehicle saying it will decelerate, you must ascertain that yourself. What if it were you who was to decelerate, how do you know the other vehicle doesn't decelerate as well, just because it said it would maintain speed? The answer is, you measure it with your own sensors. Perhaps an unconnected deer (or an unconnected child!) jumps out into the road just past the intersection. The other car slams on its brakes near the intersection. You cannot rely on the pre-established protocol. Perhaps they communicate this change of plans to you. But there is a lag (or worse, buffering). Even a fraction of a second is too much. Your vehicle must detect the other's change via sensors (which are always faster than communications, just try to beat the speed of light) and react accordingly (decelerate/ accelerate/ swerve/ brace for impact).

The algorithms, even if coordinated, would need to be able to resolve the potential conflict without communicating. To illustrate conceptually. Each vehicle, if it believes it would reach the conflict point first (to, say, 8 decimal points of precision) accelerates, if it believes it would reach second, it would decelerate. If one vehicle accelerates, and the other vehicle decelerates, we have harmony, and can avoid the collision as each vehicle continues to update velocities and speeds in reaction to the other vehicle's behavior until the possibility of conflict is avoided entirely.

Now, if all vehicles were centrally controlled, what would happen? While this might appear to improve safety (if the central algorithm is indeed safe), it does so at huge cost. The prospects and magnitude of systemic failure just increased enormously. Any bug, any hack could shut down all transport or cause multi-vehicle collisions. This seems terribly unwise.

7.3 *The Death and Rebirth? of Connected Vehicles*

So why this recent interest in connected vehicles from the US government? It comes from the same people who were pushing Automated Highway Systems (AHS) in the 1990s. It only worked on dedicated infrastructure with dedicated vehicles. No one would build dedicated infrastructure if no one owned dedicated vehicles. No one would buy more expensive dedicated vehicles in the absence of a large network of dedicated infrastructure. Full AHS was a great technology with no deployment strategy, it was a classic chicken-and-egg situation with no interim steps.

This was obvious to some of us in the 1990s, but nevertheless AHS was funded until after the technically successful NAHSC Demo (Figure 7.1), at which point it was cancelled. Certainly there were some autonomous technologies mixed in with the more connected (platooning) technologies, and some of those have reappeared, so we don't want to imply the research program was a total loss. In contrast, most progress in automated vehicles comes from outside the traditional transportation community, namely the roboticists. Their demos were funded not by the US Department of Transportation, but by the more outward looking Department of Defense, which supported the series of grand challenges described in Chapter 6.

In short, connected vehicles, if used for information, can be a benefit. If CVs are to be used for control, they are at best a luxury, and possibly a threat, but definitely cannot be relied on. They are neither necessary nor sufficient for safety. Autonomous vehicles, designed with the appropriate algorithms, in contrast are both necessary and more likely to be sufficient for safety (as human-driven vehicles have already proven themselves unsafe).

The effects of autonomous vehicles are much more profound than connected vehicles, as connected vehicles are only especially useful in the presence of other connected vehicles, while autonomous vehicles are valuable through the transition period when most vehicles are neither connected nor autonomous.

In the end, all vehicles may be both autonomous and connected, but it is far more important they be autonomous than they be connected. Fortunately, that is the sequence in which the technology will be meaningfully deployed.



Figure 7.2: Connected Vehicle Concept. Source: Florida DOT. Note there are sidewalks but no pedestrians in this worldview.

8

MaaS Transport



Figure 8.1: Subarushi. Photo by Kevin J. Krizek.

Robert Fulghum's 1988 book *All I Need to Know I Learned in Kindergarten*¹ explains how the world would be improved if adults adhered to the same basic rules as children (i.e. sharing, being kind to one another, cleaning up after themselves, and living "a balanced life" of work, play, and learning). But the first one, sharing, is relevant for transport infrastructure, the way it is used now, and how it will likely be used in the future.²

Outside of the things we talk about buying at the 'store' in Chapter 11, households mostly own stuff they do not deplete on a regular basis: homes, cars, bikes, lawnmowers, skis, or audio records. Those physical things that are only periodically needed, are rented or borrowed (e.g., library books, fertilizer spreader, pickup truck, inflatable castle). Items privately owned become dated and often antiquated. Those items that are rented may be run-down

¹ (Fulghum 1988).

² Thanks to Kari Watkins of Georgia Tech for the idea of linking Fulghum's book to transport challenges.

from use, unless the fleet or stuff receives considerable turnover.

As physical objects (rather than virtual) one person's use prevents someone else's use. Still, most of the time, nobody was using the object. Cars, for instance, typically remain unused 23 out of 24 hours in the day. Pursuing a triathlon career in his early 30s, Kevin lacked convenient travel to races and swimming practices. He therefore purchased his first car for \$700 – a 1981 Subaru that he later painted with fish (subsequently labeled the Subarushi, see Figure 8.1). The beloved Subarushi sat on the street outside his home unused all but 3 hours per week. This level of personalization is impossible in a rental vehicle (though may make rentability higher). In the same way this car sat underused, guest bedrooms rarely see guests. We suspect the bouncy castle sees jumpers even less often.

But big (and real-time) data creates marketable assets from under-used possessions. People still need physical things (those things comprised of atoms), but increasingly they demand virtual things (composed of bits, as described earlier). Either way, both are increasingly shared. Dubbed collaborative consumption, the basic idea is that things can be shared rather than individually owned (e.g., one rents hotel rooms and cars rather than buying condos and vehicles when on travel; it is now common to rent music, videos, and books).

Previously cars, taxis, and hotel rooms were rented from companies which could achieve large economies of scale. Now it is possible to rent couches and cars and rides from individuals with excess capacity. The degree to which economies of scale outweigh the network effects of distributed suppliers awaits to be seen. We roll out four dimensions of sharing – cars, rides, bikes, information – that have emerging implications for transport.

8.1 *Sharing Cars*

While living with his family in Italy, Kevin was carless; his family therefore used the town's Hertz, renting a car once per month. David did the same thing while a graduate student living in relatively high-density Berkeley, California using the neighborhood Avis once a semester. Getting to the agency in both cases was a hassle; the contract paperwork was a nuisance; the continued uncertainty over the rental agreement was frustrating. Resentment built up and the relatively high rate led to infrequent use. Alternate destinations were chosen, owing to the availability of reliable public transport.

'Carsharing' is a warm and fuzzy name for modern car rental

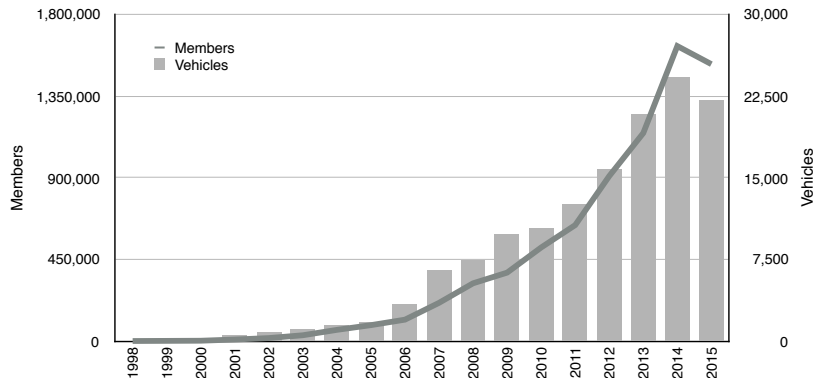


Figure 8.2: North American Carsharing 1998-2015. Source: (Shaheen and Cohen 2015).

services. People are ‘sharing’ the car just as they share a hotel room – by paying a third party and using it at separate times.³ In most US carsharing services, the ownership is by a private for-profit company (a few are non-profits and the for-profits may not actually be profitable); the service is not owned by its members. They employ mobile information technologies to avoid the repetitive contract negotiations that were once common when one wanted to rent a multi-thousand dollar vehicle from a multi-national corporation.

There are notable differences between traditional and modern car rental. First, the car is reserved via a website (or more recently, a smart-phone app) and unlocked via a special member card or the phone itself, no real-time intervening labor is required between you and the car. Second, the newest of these services allows you to pick up and drop off your car at any legal on-street parking space, no longer only at special stations or locations.⁴ Third, the rentals can be by the number of minutes, rather than days, so cars may be less expensive to rent for a short trip. In the US the first break-out company in this sector was Zipcar, which adopted a model widely used in Europe⁵ and went public in 2011, but still contained some inconveniences.

As a member of a two-driver, one-car family, David used Zipcar for about a year, but stopped due its inconvenience and cost. While his experience was limited (he used it for only a handful of trips), there were several problems. First the station was inconvenient from his house, the pick up and return location for the car was a parking space on campus, more than a mile from home. Second he had to know exactly how long was the trip, since overage charges were some \$50. From the Zipcar perspective, with such a thin fleet of vehicles, the overage charge was essential to guarantee the car would

³ Carsharing is by-and-large in the US context not even analogous to a time-share, where different people do share ownership of a property, but get to use it at different times.

Zipcar was originally founded by Robin Chase and Antje Danielson in 2000; Danielson was forced out in 2001, Chase in 2003. Zipcar went public with 8,000 cars, 500,000 members and \$186 million in revenue. Never profitable, it was acquired by Avis in 2013 at about one-third its 2011 market capitalization. Avis assessed its net present value at over \$500 million of profit over the discounted future.

⁴ This varies by city, so in Minneapolis, cars are on-street, in other cities like Boston, restriction affect this.

⁵ For more on carsharing: (Fallon 2011; Alspach 2013; Duhaime-Ross 2014).

be available for the next renter, but to avoid being late, the renter had to reserve the car for a longer time period. Third, the technology was a bit wonky, leading to risk of having no car available at all.

Car2go (and others) all strive for various improvements on the same theme, most notably the ability to park anywhere rather than at a station.

Car2go, a newer service than Zipcar, worked better for users. At its peak, some 535 cars were deployed throughout Minneapolis and St. Paul, so a user could reserve a car (no more than 30 minutes in advance) within walking distance. The app will show directions to the car.

Once you enter the car, find the key, turn the ignition, fill out a brief survey on car quality, and off you go. Unlike Zipcar, car2go bills by the minute. When you are done, you check out from the car.

Car2go uses Smart Fortwo vehicles, which are the smallest and least expensive commercially available road-worthy vehicles in the US. The Smart Fortwo, despite being a unit of Daimler, best known for the Mercedes Benz, gives you the feel of the road.⁶

New economic models include RelayRides, which allow individuals to rent their own car, and is perhaps best suited to airports where cars are otherwise parked for a long time, and CarNextDoor.

Like most automakers, BMW is entering the carsharing market with DriveNow. Ian Robertson with the company says “As a mobility provider, the BMW Group is not simply an automobile manufacturer.”⁷ BMW also combines carsharing with leases, so for instance, you can lease a small EV during the week and get access to a larger vehicle on the weekend.

The importance of carsharing is not as a replacement for rental cars, which are still standard in their traditional market of airports and auto replacement during servicing – though that may change as well. Carsharing also is not cost-effective as a replacement for daily commuting trips. However if you walk, bike, or take transit to work, it might be good to replace owning a car, or second car, for the occasional (say weekly) trips that are too far to practically walk or bike, and too inconvenient to take a transit system that serves downtown well and little else. In crowded urban areas where paying for parking near your home is a real financial burden, carsharing is more promising than most of America where parking is practically free.

The car-shedding question remains: how many households will surrender a second (or first) car for the occasional trip?⁸ Is the market thick enough that the likelihood of finding a car nearby is

⁶ Smart is a unit of Daimler, and US sales help them satisfy Corporate Average Fuel Economy (CAFE) standards, fuel efficient Smarts are averaged with less fuel efficient and much larger Mercedes.

When David once told a Honda sales person that a test ride was bumpy, they said Honda designs their cars that way because of Honda’s “racing heritage,” so we can chalk up the feel of the road to Smart’s racing heritage. On the city streets of Minneapolis, where the pothole is more common than an actual street surface, this is not a good thing. Still the convenience of the service outweighs the chintzy vehicle.

⁷ (Vijayenthiran 2011).

⁸ There are several studies on car-shedding due to carsharing. It is too early to form a conclusion, as early adopters may behave differently than later adopters. (Stasko et al. 2013; Ter Schure et al. 2012; Shaheen and Cohen 2013).

high enough that it is reliable enough to use? With car2go there is no guarantee there will be a car within walking distance. Efforts to rebalance the fleet can be costly. This is where other services (taxi, transport network companies, transit) come in as backups. This is also where autonomous vehicles can be important.

Nevertheless, people prefer not to think about every transaction. If they are charged per use, they use less. But they are less happy and more determined to get a car of their own to avoid transaction costs. Individually owned cars of course have costs of their own, but they are less frequent and less obvious. If the charges are invisible people may not think about them. Just as we went from terminals and mainframes to personal computers, and internet cafes to internet at home, we went from trains and transit to private transport once we could afford it. The cost savings will have to be considerable for most people to want to go back. But habits are easier to form in the young. An urban college student who joins car2go may keep it after they graduate while they remain city-bound.

The best market for car2go may be the urban hipster – enough money to afford, enough transit savvy to get to work and back with minimum hassle, enough childlessness to have a simple schedule, enough desire to signal greenness to avoid owning a car, but enough sense and desire for dates in the country or trips to Ikea to recognize the occasional need.

Car2go is expanding in some places globally, but in many others, that market is not good enough, and car2go has retrenched; it has withdrawn from Minneapolis, San Diego, and Miami in the US and London and Birmingham in the UK.

Car-sharing is a network-effects driven business, for it to work, the access costs must be low, generating demand, which will increase vehicle availability (as suppliers respond to demand), which will lower access costs, which will increase demand. Given the idleness of existing car2go vehicles (which were rumored to be as idle as private cars in Minneapolis), they clearly could have accommodated more customers on the existing fleet. Access costs were insufficiently low to get this positive feedback network effect going. Perhaps a greater investment would have juiced the market, it is unclear. At the time of its demise in late 2016, gasoline prices were exceptionally low, the economy was at the peak of expansion, so people readily buy and drive private cars. In withdrawing from Minneapolis, car2go specifically complained about taxing, which is an element. Clearly carsharing should not be taxed at the same rate as rental cars, which are aimed to extract money from out-of-towners ('taxing foreigners living abroad' in the famous

words of Monty Python) who don't vote locally. This is a case of public policy not catching up with changing technology.

It should also be noted there is an implicit subsidy to car2go, which uses Smart ForTwo vehicles. Smart is a subsidiary of the German company Daimler-Benz, and the good fuel economy of Smart cars offsets the guzzlers produced under the Mercedes marque in the US's federal corporate average fuel economy (CAFE) standards. Yet the market was not strong enough. In large part this is due to the rise of ride-hailing apps, as discussed in the next section, which provide a cost-effective substitute so-long as they remain heavily subsidized by venture capital funds.

Figure 8.2 shows trends on carsharing in North America. It is not clear where market saturation is, and whether the dip in 2015 (prior to some of car2go's retrenchment) is just a data issue or indicative that perhaps ride-hailing apps are stealing some carsharing thunder. Notably carsharing company Shift shuttered in Las Vegas in mid-2015.⁹

⁹ (Totten 2015).

How does Lyft (or any other Ridehailing / Transportation Network Company) work? From the perspective of the user (1 and 2 are one-time) the following is the sequence:

1. Download the App.
2. Enter the required info
3. Open the App and summon a Ride.
4. Get in the Lyft vehicle when it arrives (the driver will usually call to confirm pickup location/time), it has a small mustache in the window.
5. Tell the Driver the Destination – You can enter this in the app as well, though it doesn't affect who picks you up (yet) apparently. This is an opportunity for efficiency, as drivers, for instance, may be happy to go towards their home near the end of a shift, but not away. On the other hand, that might lead to too few drivers "bidding" on prospective customers.
6. Ride
7. Get out of the Car.
8. Check App to rate the driver. Payment is automatic unless you want to change your payment.

8.2 *Sharing Rides*

If carsharing was a warm and fuzzy name for modern car rental services, 'ridesharing' is a warmer and fuzzier name for modern taxi services. You might have thought ridesharing was the same as carpooling. And it is, if you think of the drivers as your friends giving you a lift (or in the name of one company a Lyft), not for money, but for a voluntary donation or paying for half the costs, like the carpooling service and app Carma enables. Whether this attempt to skirt the rules and regulations of taxis succeeds is a battle to be fought out in thousands of local markets globally. In markets where an agreement has been reached, the donation results in an actual charge and the process – enabled by smartphones – is taking off.

The terminology for this service is still in flux, sometimes the terms 'ridehailing' or 'ridesourcing' are used rather than 'ridesharing' to cool and de-fuzzify it. 'Ridehailing' avoids ambiguity.

The car you get with Lyft (or UberX) is the driver's personal car, not a fleet vehicle; it varies. David's first Lyft ride and Kevin's second UberX was in a Mercedes.

Kevin's first UberX ride was at the San Francisco Airport from Raffaello who telephoned saying he was in the white Prius at the stop-light by the end of the airport terminal. Kevin proceeded to the supposed Prius and open the back door to enter the car – much to

a woman's astonishment and disdain. He walked to the next white Prius and fortunately found Raffaello (and the correct car).

These social dynamics matter to services like Lyft. In contrast with traditional taxis, the passenger sits shotgun (in the front row passenger seat), and is expected to have a conversation with the driver (which happens in some taxis, though not always). Anecdotally, it appears people who drive for Lyft are more likely to be (though not universally) American citizens or long-term residents, and since they own their own car, less likely to be poor, recently landed immigrants who comprise the taxi drivers in many cities.

Lyft is in many ways simply an app with a back-end (rather, 'cloud-based') dispatch service. They claim to be a "transport network company whose mobile-phone application facilitates peer-to-peer ridehailing by enabling passengers who need a ride to request one from drivers who have a car." They insist the drivers are independent (as are the riders). The difference between this and a taxi dispatcher is thin. A taxi is "a car licensed to transport passengers in return for payment of a fare, usually fitted with a taximeter."¹⁰ So for taxicabs, the arrangement between the rider and the passenger is mediated by the government (which licenses the vehicles).

¹⁰ Source various, including ([Dictionaries 2017](#)).

Are Lyft drivers licensed to transport passengers for payment? This is a major point of contention. They are licensed drivers, and any licensed driver (above a certain age and level of experience) is eligible to carry passengers. The cars are private cars (at least sometimes) though that is little different than how taxis operate in other parts of the world. Many Singaporean taxi drivers will take fares when going between where they are going anyway, but otherwise treat the taxis as a personal vehicle.

Lyft now does jitney (shared taxi, dollar van, informal transport) type services, dubbed Lyft Line. (Uber has the similar UberPool) These serve either one pickup going to multiple destinations, or multiple pickups going to one destination, or multiple origins to multiple destinations, and compete with both taxi and public transit. (Though it would not be exactly fixed routes, one could imagine regular runs with a known coterie of passengers). This is at a lower rate than the traditional single party, taxi-like service. While these services are at the time of this writing only in San Francisco and New York, Lyft now claims that Lyft Line comprises 50% of Lyft's rides in San Francisco and 30% in New York.¹¹ (Not all of Lyft Line customers wind up in a shared ride, they just indicate a willingness to for a lower fare, and get the lower fare regardless of

¹¹ ([Bregman 2015](#)).

whether another passenger can be found).

Typically at busy times, these ridehailing companies will either face a shortage of drivers, or implement ‘surge’ pricing, using higher prices to manage demand and induce drivers. Another solution would be to implement ‘compression’ mode, whereby travelers shared rides with strangers to better use seat and driver capacity.

The ease of making ride requests and payments is what drives many folks to choose Uber or Lyft over traditional taxis.

We suspect differentiating status and class is another important element. Users are hip enough and wealthy enough to use the new technology and not have to sit where others from other, less tech-savvy classes have sat before. As these services become widespread, humans will undoubtedly develop new forms of elitism.

Venture capitalists believe these will be very successful companies. Uber has been valued at over \$70B. While we believe ridehailing is a useful market product, we remain skeptical of this valuation, if only because there are so many competitors (including of course Lyft, as well as BlaBlaCar, Didi Kuaidi,¹² Gett, Curb, Hailo, Blacklane, Sidecar, Zimride, iHail, and Flywheel, among others) and the stickiness of riders and drivers to any particular company is weak and their limited advantages to larger services over smaller ones.¹³

The competition from the new entrants has driven taxi companies to step up their game, a number of the services listed are better interfaces to traditional taxi. Drivers are already simultaneously on multiple networks, so the expected pickup time doesn’t vary much from one app to another. Waze, a subsidiary of Google, is testing a true peer-to-peer, real-time, no payment ride-sharing service. Shuddle, KangaDo, and HopSkipDrive aimed to be the “Uber for kids.”¹⁴ (Though Shuddle is now deceased).

Lift Hero targets seniors. SheTaxis and Chariot for Women aim to be an “Uber for Women.”¹⁵

8.3 *Sharing Bikes*

A recent popular internet meme¹⁶ noted that in Europe, bicycles were outselling cars.¹⁷ We were surprised it was news, since it is true in the US as well, and it seemed obvious to us (particularly for Kevin who was rumored at one point to have a quantity of bicycles well into the double digits). The National Bicycle Dealers Association (NBDA) reports¹⁸ annual bike sales on the order of 18.7 million for 2012. In contrast, US car sales are on the order of 8

¹² (DeAmicis 2015).

¹³ A longer discussion of our skepticism is at (Levinson 2014b).

¹⁴ (French 2015; Zimmerman 2016).

¹⁵ (Hatmaker 2014).

¹⁶ Apparently Based on (Calamur 2013).

¹⁷ We use the term ‘bike’ to mean the traditional human-powered ‘bicycle,’ unless otherwise noted as in e-bike or motor-bike.

¹⁸ (National Bike Dealers Association 2012).

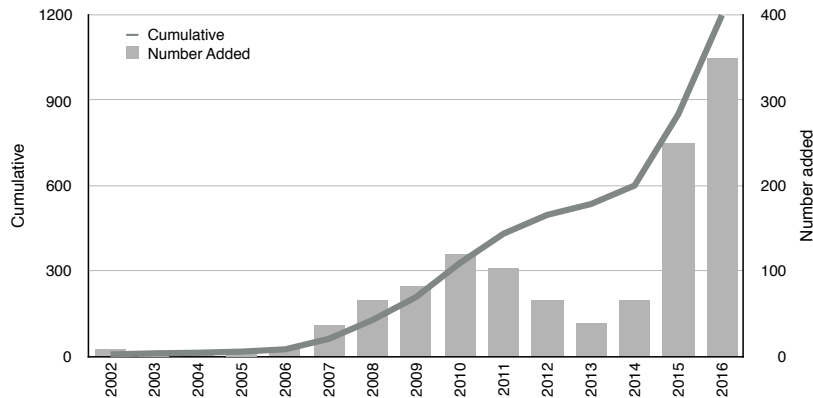


Figure 8.3: Growth of Bikesharing Systems Globally 2002-2016. Source: (McCarthy 2016; Meddin 2017).

million, along with another 8 million light trucks. So where are all these bikes, why are they not seen more on roads everyday?

BIKES FOR KIDS. Many of the bikes sold annually are for children (5.7 million of the 18.7 million are below 20 inches wheel (50 cm)), but even so, 13 million are 20 inch and above wheel size, and 13 million is still much bigger than 8 million cars (and near 16 million light vehicles, note also that many light vehicles are not for personal use). Even just inspecting specialty bike shops, which sell at the higher end, that's nearly 3.1 million bikes per year, which while less than cars, is still a pretty big number.

Yet, the volume of trips by bike and certainly miles by bike are much lower than by car and are not poised to overtake in the US. We don't even see 3.1 million bike commutes daily in the US. The American Community Survey reports 865,000, so these are more likely for recreational than utilitarian purposes.¹⁹

THE SHORT LIFE OF BIKES. Another reason for this statistic is that bikes don't last as long as cars. The average US car on the road is 11.4 years; while no similar data exists for bicycles, it must be lower, especially given the higher sales. At 18.7 million bikes per year there would be 1 bicycle for every person in the US after 16.7 years of sales, so the average age would be about 8.4 years if everyone had a bike and there were no losses, and surely that isn't true. This again is in large part due to the growing up of kids.

So lack of bikes does not seem to be a problem, but bikes where you want them may be. If I didn't take my bike to work, I can't use my bike for a lunchtime ride at work. If I am a tourist, I probably didn't bring a bike with me. Wouldn't it be great to just get a bike

¹⁹ ACS numbers are undoubtedly an under-report of bike travel, but the number remains small. (Schoner and Lindsey 2015).

when and where I want it, and abandon it there at the end of the trip. Well, it is not quite modern carsharing, but widely dispersed bike stations make this closer to possible. As shown in Figure 8.3, bikesharing systems have grown in many cities worldwide.

STATION-BASED BIKESHARING. Bikesharing, the modern version of bike rentals, (just as carsharing is the modern version of car rental) has both a membership and per-use model. Typically a member signs up online, gets an electronic key in the mail, and can visit a bikeshare station in their system and simply insert a key in the slot next to the bike they want, and pull it out, and remove the bike. They then have, say, 60 minutes to use the bike before it needs to be returned to a station (any station, not just the one it was borrowed from). A one-time user has to insert a credit card. These measures ensure the bicycles are returned and not found in the bottom of a nearby river, the sad outcome of early free bikesharing schemes.²⁰ The bikes, while functional, are unlikely to be a model a regular bicyclist would purchase. They are especially heavy, and only 3-speed, so the risk of theft is relatively low.

²⁰ Which isn't surprising, by definition socialists don't respect property.

STATIONLESS BIKESHARING. Chinese companies have pioneered stationless bikesharing, where the bikes can be dropped off anywhere within the designated parts of the city, and located via GPS and an app. The bikes are locked and unlocked with an app, and each member has put down a deposit in advance. Hundreds of thousands of these bikes, from different vendors, can be found in each of many large Chinese cities. This upends some of the weaknesses of station-based bikesharing, but it is not clear whether the model translates outside of China. It is being tested as of mid-2017 in Melbourne, Sydney, and Manchester. E-bikes are also on offer in some cities.

Bikesharing is about active transport as much as recreation, and a way of connecting these two things.

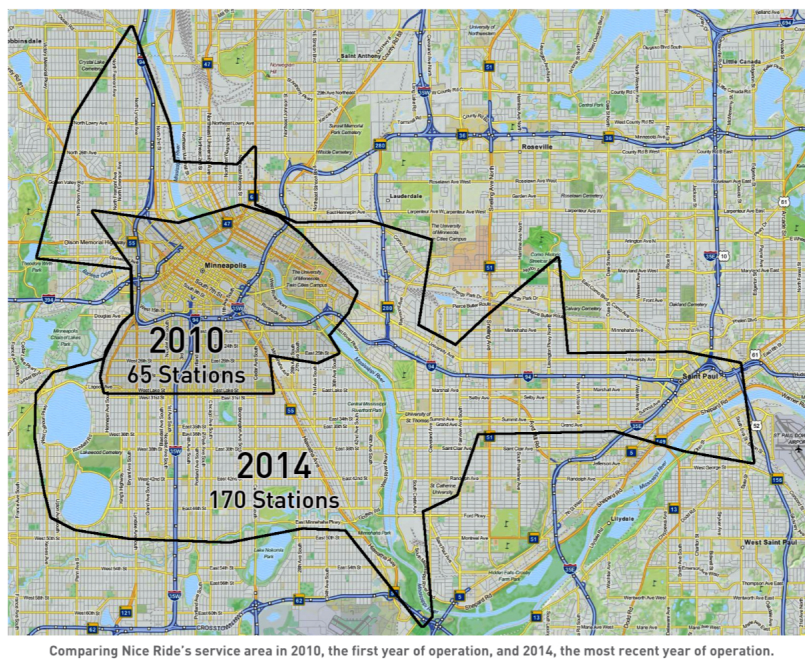
Maturation in the number of systems is a good thing in many respects. A next step, however, is to stop adding new systems in favor of increasing the services of existing systems, inter-connecting and inter-operating (maybe even consolidating some). A related aim is broadening the subscriptions globally, so that memberships can be used on any system in the world.²¹

NiceRide, the largest bikesharing system in Minnesota, has shown continuous growth from 2010 through 2015, as shown in Figure 8.4. This is complemented by a significant increase in those

²¹ Few people will of course take a bikeshare bike from Minneapolis to Chicago, but Minneapolitans should automatically be able to use the Chicago system (and vice versa). And like the electric inter-urban users of yore (one could take an electric inter-urban (trolley) from Elkhart Lake, Wisconsin to Oneonta, New York, it was said), one should be able to bike share between major places, even if transferring bikes periodically.

years in bicycle-dedicated infrastructure, including separated bike-lanes. More bike traffic is expected to have a safety-in-numbers property that crash rates per bicyclist will decline with an increase in the number of bicycles.

Bikesharing can function as an extender of transit service, as people take transit, transfer to a bike-share to reach a final destination (or for recreation), and to return to the transit stop. With station-based bikesharing, this requires a station at the destination end, or the destination to be short duration. With stationless bike sharing moving from speculation (in the first two editions of the book) to reality, the flexibility and thus usefulness of the system greatly increases.



Comparing Nice Ride's service area in 2010, the first year of operation, and 2014, the most recent year of operation.

Figure 8.4: NiceRide's Service Area 2010-2014. Source: (Dossett 2016).

8.4 Sharing Information

The advice from Kindergarten alluded to above mainly applied to sharing physical items. A contemporary update relates to information: my information could be used to augment your information. Sharing information is like a rising tide that floats all boats and big, real time information (data) creates new knowledge to improve decisions.

If data are pieces of information, quantitative or qualitative, then what the hype machine is now terming 'big data' is really just more

data – and lots of it. The transport industry has long employed loop detectors in the road to count cars and provide information to traffic signals. Traffic signals were first installed in Cleveland in 1914, and there are more than 300,000 traffic signals now operating in North America, affecting most daily trips. While great progress has been made in terms of passenger safety and road efficiency by this technique, there are still some limitations. Improperly operated traffic signals cause excessive delays that sacrifice productivity, waste fuel, and pollute the air. While side collisions are reduced, rear-end collisions are increased at signalized intersections. Dissatisfaction in intersection operation has become a serious problem faced by traffic operator. Traffic signals suffer from improper settings, delayed maintenance, and malfunctions.

Travel diaries, via self-reported information, have been around since the 1940s. But there are now sensors everywhere, and users – and cities – are just beginning to exploit this information. Travelers themselves are now the probes with GPS units and wireless communication enabling everyone to know (in principle) near real-time speeds, traffic conditions, and transit schedule adherence. Digital traces of everyone doing everything are everywhere, including who is doing what, buying what, searching for what and even physically where they are going. Furthermore, it is often crowd-sourced and sometimes open. When it is not, legal issues abound.

Relatively standard practices from e-commerce and business analytics are infiltrating domains of public service provision and urban governance. Generic commodities are being replaced with identity preserved goods.²² You are no longer buying nondescript Grade 4 Durum wheat, but a 5 lb (2.2 kg) bag from a bushel of Durum wheat from a particular row on a particular farm, planted and harvested on particular dates, grown from particular seeds, with known fertilizers and pesticides documented. The meta-data about your product will be as detailed as the product itself.

Logistics firms have long used scanners to track goods through the distribution chain, with a high degree of success. That same level of knowledge is slowly percolating through public sector transport organizations. We no longer lump like things together without knowing where they came from, where they are going or who bought them. Under monikers such as ‘smart cities’ and ‘civic hacking,’ the use of centrally available data has made inroads into the urban policy sphere, moving from an e-government tool that aimed to increase public sector transparency into new forms of public-private partnerships or urban laboratories that vest analysis

²² The television show *Portlandia* satirizes this in the skit “Is the Chicken Local?” <https://www.youtube.com/watch?v=ErRHJLE4PGI> (The Chicken was named Colin).

and problem-solving in formal or informal institutional arrangements outside of city agencies.²³

For many mobility options,²⁴ we now have instantaneous knowledge of how soon a taxi or ridehailing service will provide a pick up. Specific (and sometimes accurate) apps tell travelers when the next bus will arrive. Via Twitter feeds, it is possible to even know in advance if there is space on the bus for our bike. Because GPS systems have real-time traffic, sitting in traffic owing to lack of knowledge about crash or construction delays can be a thing of the past. Plans can be changed on the go. Services such as Waze (now owned by Google), TomTom, Inrix, and Here are competing in the traffic information market.

In addition to providing value to the traveler, new smartphone-based and vehicle-based sensors will be valuable to transport agencies who are woefully uninformed on how people actually use their systems. This information will prove useful not only for planning, but even for real-time operations and controls, identifying information that will feed algorithms that decide how to time traffic signals or dispatch additional buses. Apps which crowdsource vertical acceleration information and GPS locations from smartphone sensors are already useful for automatically providing agencies about road quality, like where is the latest pothole.²⁵

At the personal level, The “Quantified Self” suggests that the outputs of many new sensors will be fed back to the individual traveler. Yingling Fan of the University of Minnesota notes that information about travel can lead to behavioral interventions.²⁶ She identifies three stages: *awareness*, informing the traveler of their environmental impacts, *motivation*, describing the benefits of change, and *action*, providing the tools to change behavior (e.g. making it easy to rent a bike or take transit). Health apps of various kinds are an early version of this, showing the user the number of steps taken so far, or modes that they used.

Communities are still putting this all together to make it work as well as it does in the pitch to the venture capitalists. But the direction is clear: the world is in the process of transforming from one of ignorance and static plans to one of planning (and re-planning) travel on the fly with confidence. Plans are more dynamic. With more confidence, people can freely venture farther afield, away from their familiar haunts, in search of the novel. Agencies can now better monitor conditions and make better short-term predictions. Congestion and late buses will be less of a surprise. Cumulatively, increased – and shared – information is

²³ (Karvonen and Heur 2014).

²⁴ (Kitchin 2014).

²⁵ (UK Government 2013).

²⁶ Fan, Yingling (2016) Quantified Self and Quantified Networks (Chapter 5) in (Levinson et al. 2016).

mobilizing people in unforeseen ways.

8.5 *The Future of Sharing: Cloud Commuting*

²⁷ The term was probably coined by David in his blog (2008-08-23) <https://transportist.org/2008/08/23/cloud-commuting/>.

The term ‘Cloud Commuting’²⁷ refers to what we may now think of as Silicon Valley’s promised future where you don’t own a vehicle, but instead summon a ‘shared autonomous electric vehicle’ (SAEV) on-demand, in real-time, right-sized for your party, maintained by a fleet operator, and not just for special trips, but for your daily commute and errands. This future contests with the ‘private autonomous electric vehicle’ (PAEV) for hearts and minds. As we discuss in Chapter 13, both are possible.

For communities where densities are relatively low, incomes high, and thus taxis scarce, the most reliable strategy for timely point-to-point transport is for people to maintain personal transport close at hand. Cars and bikes, which they own, are parked at their homes, workplaces, or other destinations. But with more widespread use of information technologies, ownership and possession are no longer necessary prerequisites for on-demand mobility. Widely called the ‘sharing economy’ or ‘collaborative consumption,’ its present-day manifestations in transport: carsharing and ridehailing are viable if not widespread. Couple these technologies with autonomous vehicles discussed in the Chapter 6, and one arrives at what we term ‘cloud commuting’ – the convergence of ridehailing, carsharing, and autonomous vehicles.²⁸

²⁸ This idea is also discussed in (Enoch 2015).

More formally, this range of options can be termed Mobility-as-a-Service (MaaS). While nascent today, clearly big players are placing big bets that this will be a big change in how people travel. It is this which explains Uber’s multi-billion dollar valuation.²⁹

²⁹ Uber’s valuation has risen steadily as we write this, at the first edition it was in our view overvalued at \$40B. In December of 2015 it was \$62.5B. (Kokalitcheva 2015).

A vehicle from a giant pool of autonomous cars operated by organizations based ‘in the cloud’ would be dispatched to a customer on-demand and in short order, and then would deliver the customer to her destination (be it work or otherwise) before moving on to the next customer. Even more efficiently, it might pick-up or drop-off some additional passengers along the way and may offer customer specific features, though this depends on the size of the vehicle, as discussed in Chapter 10.³⁰ We quickly run down implications as MaaS emerges.

³⁰ Vehicles may likely have customer’s preferences pre-loaded (seat position, computing interface, audio environment, video entertainment, computer desktop).

SMALLER, MORE MODERN FLEET. The customer benefits by not tying up her capital in vehicles, nor having to worry about maintaining or fueling vehicles. The fleet is used more efficiently, each vehicle would operate at least 2 times (and as much as 10

times) more distance per year than current vehicles, so the fleet would turnover faster and stay more modern.

Fewer vehicles overall would be needed at a given time. It is likely customers would need to pay for this service either as a subscription or a per-use basis. Advertising might offset some costs, but probably not cover them. This includes both advertising to the customer in the car and using the car as a roving billboard.³¹ However retail stores (if they survive) might subsidize transport, as might employers, as benefits for customers or staff.

³¹ One of David's students founded Admo, peer-to-peer car advertising. <http://admocar.com>.

VEHICULAR VARIETY MaaS allows a variety of vehicles to serve customers, rather than a single, least common denominator model. This right-sizes the fleet to the customers, and should lower costs, space use (see Chapter 9) and energy use.

COVERAGE, LOGISTICS. Like traditional fixed-route transit, MaaS will function better in urban areas than rural areas. Response time will be shorter (potentially faster than getting a parked car); size and variety of the vehicle pool will be greater; parking in high value areas becomes less troublesome. MaaS will also fit better for nonwork rather than work trips, as the regularity of work increases the value of either vehicle ownership or regularly using micro- or macro-transit versus renting by the trip.

Autonomy solves the localness problem facing existing carsharing services, since the cars come to you. Like current bikesharing systems, there would need to be load balancing features, so the cars were pre-dispatched to areas of anticipated demand, and maybe coordinated carpooling at peak times.

LABOR. Automation also structurally transforms the labor relations of ridehailing services and transit, making it potentially both massively more abundant. In general, automation is accompanied by unemployment and social dislocation in the sectors it affects (in this case transportation), with associated spillovers, as workers need to find new skills and jobs in new sectors. Given this is not an overnight change, but occurs over decades, it will appear important but not urgent, and much of the labor force reduction will occur through attrition and lack of new hiring.

PAYMENT STRUCTURE. An interesting aspect of this from the perspective of travel demand is that with MaaS, people will probably pay by the trip, either directly, or through choosing the right plan of service roughly proportional to use. While the average

cost of car ownership, now a quite significant share of household expenses, goes to zero for those who join this system, the out-of-pocket marginal cost per trip rises quite significantly. The implication is fewer trips assuming people give up on vehicle ownership. People paying by the minute or the mile will want to reduce trip distances.

ELECTRIFICATION. Autonomous and shared vehicles will interact with electrification. A rental service of self-driving autonomous vehicles, that are ordered on-demand may provide you a fully charged electric vehicle for your trip. Much like the Pony Express, which swapped horses rather than requiring riders to wait for their own horse to rest, the service may provide a replacement vehicle mid-trip rather than requiring you to wait around to charge your vehicle.³² There is no requirement that cloud-based, self-driving vehicles be electric, but as cars get smarter they should be able to charge themselves, alleviating some of the concerns associated with EVs.

³² Assuming range issues have not been resolved.

STREET DESIGN. Streets designs will need to accommodate pick-up and drop-off as a major feature, so curb space will need to be rearranged so people know where to meet their car (and vice versa), so they don't get into the wrong white Prius. While we lose the need for parking, we might think of channelizing roads more like airports or multi-way boulevards than the monolithic pavement they are today. Street design is discussed more in Chapter 14.

8.6 *Sharing vs. Ownership*

Sharing – be it cars, bikes, boats or information – has strong network effects driven by convenience (a characteristic the time-starved seem particularly mindful of). But, macro versus micro transit discussions in Chapter 12 bring up matters of economies of scale versus economies of scope. There's a role for both.

For example, one is more likely to use carsharing if more neighbors use it, since that makes it more likely there will be a car in front of one's house, workplace, or wherever, when it is desired. Reducing vehicle access time from 10 minutes to 5 minutes, or 5 minutes to 2 minutes is significant, especially when most trips are only 20 minutes long.

There are many blocks in Minneapolis (1100 miles of street), so moving from some 500 cars in Minneapolis and St. Paul to some 5000-10000 (as a rough approximation of where it needs to be so

a member doesn't have to walk more than a block to find one) is a 10 or 20-fold expansion over the peak of car2go. Finding one of Minneapolis's 300 cars (assuming the other 200 are in St. Paul) in a city of 58 square miles meant about 5 cars per square mile. As of the first edition of this book, there were 6 cars within a 10 minute walking distance (an area of about 50 very non-square blocks), and 1 within a five minute walk of David's house. On 1100 miles of street, this is not going to be a dominant mode without significant expansion. But 5000 cars is less than the several hundred thousand registered in Minneapolis, and could replace many of them.³³

The car2go model did not put in enough capital, nor did it have enough demand, so there was a car waiting on every block. To do so is no small step, and may require automation.

There is also the rise of ridehailing apps like Uber and Lyft, which are only slightly more expensive and loads more convenient than carsharing for many trips. That they are only slightly more expensive is due to tremendous venture capital (VC) subsidies, which are great to exploit as customers, while they last. This also did not help carsharing.

As with any social network, it is not clear in advance which if any will take off. As with many networks, there needs to be a large up-front capital investment. But unlike rail transit systems, carsharing is dealing mostly with mobile capital. If the program doesn't work in place A, cars can be redeployed to place B, or at worst, sold in a used car lot. Further the programs are privately funded, which is more suited to innovation and adaptation, and accepting of failure, than publicly funded transit agencies.

The economic and environmental benefits of renting rather than owning are clear, but the sociology and the the role of regulation³⁴ remain unclear. People willingly use hotel rooms, or bikes, or library books that have been used by others before, but not, typically, cars. How do cars get transformed from an owned good to a rented service? In part this is generational. If you have never owned a car, new habits can be formed. But that type of change is very slow, perhaps as slow as generational shift. Early adopters and the carless may be quick to join. Some/many/most Americans use their cars often enough, in places remote enough, or customize their cars sufficiently that MaaS will not be advantageous in most circumstances. The question is: What is the winning fraction? We suspect the answer is related to land use patterns. Where people live in apartments, MaaS will be successful if not dominant. Where people live in single family homes, MaaS will be far less successful, though not nonexistent.

³³ Some of this information was gleaned from the car2go website (2015-04-03) <https://www.car2go.com/en/minneapolis/>.

³⁴ For forecasts of the shared economy and local regulation, see: (Rauch and Schleicher 2015).

³⁵ (National Multi-family Housing Coalition 2015) from 2014 American Community Survey.

Nationally 35% of the US population are renters and 14% are apartment dwellers.³⁵ To be clear today, not all apartment dwellers are transit riders or walk to work (about 20% do), and not all single-family dwellers use the automobile to get to work (though 96% do). Any change from a ownership-dominated to a MaaS regime will take decades, and likely be slower than the introduction of automation in the first place. Replacing the car is easier than replacing the way the car is owned or used.

Whether, when, and where fleet ownership/sharing/renting replaces individual ownership is less so. Certainly Manhattan is the kind of place this will be common, as taxis are already very important. Existing customers can easily shift, as *doing old things better* is the first step in a new technology. But most of the US is not taxi-reliant now, so is not a mere conversion but a major behavior shift. *Doing new things* is the second step.

9

Demassification



Figure 9.1: Car2go. Car2go carsharing vehicles are Smart Fortwos, the smallest car sold on the US Market. While generally car2go is allowed to park on-street on City of Minneapolis roads, this poor car received a ticket as it was parked on a road maintained by the Parks Department, a separate unit of government, a distinction without a difference for most Minneapolitans. Photo by David M. Levinson.

Technological advances have been shrinking consumer goods, and getting more output per unit of energy and matter, for a long time. Microwaves can substitute for ovens, the Walkman, the iPod, and now just a music app substitute for the stereo and boom box. Increasing productivity and usefulness is hard-coded into a Darwinian market economic system. Dematerializing from things into data is perhaps the final stage of shrinkage, discussed in Chapter 10. But even just reducing the number of atoms required to deliver a service is progress. GM for instance had a project in the 1970s, (Figure 9.2) the Lean Machine that aimed to do that, which reduced both the matter needed for the vehicle and the number of molecules needed to be burned for fuel.

Figure 9.2: GM Lean Machine concept vehicle. Photo source: Evo.



One foreseeable future involves moving less mass in the form of vehicles, and therefore consume less energy. Moving two tons of metal and plastic to transport one or two humans is excessive, to say the least. Small cars have longer range per unit battery than larger cars. The gasoline powered Smart ForTwo, shown in Figure 9.1, is one of the smallest mass produced cars on the market in the US. And while not exceptionally popular in the US (sales are under 1000 units per month), they are a hit in Europe owing largely to the fact that the costs of owning and operating cars are higher than they are in the US due to public policy like higher fuel taxes – and furthermore, space on roadways and in cities centers is a premium. Bicycles (Figure 9.3) and skinny cars (Figure 9.4) are much more efficient in terms of capacity than traditional cars

With even less mass, powered two-wheeled vehicles (motorcycles, mopeds, electric scooters, electric bikes and all the variations in-between) have been enormously successful in developing countries. Electric scooters and bikes have recently exploded in China (e.g. Figure 9.3) – resulting in mountains of disposed lead-acid batteries piling up in landfills on the outskirts of Chinese cities. Two-wheeled vehicles (mostly motorbikes) are the most rapidly growing form of urban mobility in rapidly developing cities of Asia and increasingly in Latin America and Africa. Are they stepping stones to eventual full-blown automobility? Are their safety, nuisance, pedestrian-clash impacts greater than those of traditional cars? Motorized, electric, and pedal-powered two-wheelers are different worlds, yet they overlap in their



Figure 9.3: Shared, stationless e-bike in Shanghai, China. Photo by David M. Levinson.

demands for space.

Powered two-wheelers provide an upgrade path between the inexpensive, but speed-limited bicycle and the much more expensive, and rationed, automobile. Their path to dominance has been slower in more developed countries, as they are perceived as an inferior good, with less flexibility (to carry more goods and passengers) and comfort (e.g. seats, climate control) than an automobile, which is preferred by those who can afford it (which is most adults in developed countries). The same infrastructure that supports bicycles (bike lanes, bikesharing networks, and so on) has been adapted to serve electric bikes as well, to the consternation of some bicyclists.

Yet bikes, and e-bikes are likely to remain niche modes in much of the US, and while that niche may increase in size, existing land use patterns, notoriously slow in their ability to change, contributes to a larger context that is far from conducive for cycling for the majority of trips. American consumers may be reluctant to downsize too much. Safety of vehicle occupants is cited as a concern. Until self-driving vehicles alleviate most safety risks, and as long as the US is wealthy, US cars will remain larger than average.

Interestingly on the freight side, results differ, as larger trucks are more fuel efficient (as they spread the fixed weight of the vehicle over more cargo and have less wind resistance). Adam Boies writes:

Figure 9.4: Tango thin cars share lanes, reducing capacity needs. Photo courtesy of Tango.



Figure 9.5: Toyota iRoad. Photo courtesy of Toyota



“emphasis on fuel efficiency in the light duty and heavy duty vehicle fleet is likely going to drive the weight of the vehicle segments in opposite directions. Light duty vehicles are likely to get lighter, especially as different ownership models allow for dedicated light duty vehicle fleets that focus on fuel efficiency for personal mobility. Heavy-duty vehicle fleet operators are likely to lobby for increased vehicle weight limits ... in order to reduce the energy intensity of goods deliveries. The growing disparity in weight between the two vehicle classes may necessitate increased safety measures to reduce the severity of crashes between the disparate vehicle classes.”¹

¹ Boies, Adam (2016) Electrification and Alternative Fuels (Chapter 6) in (Levinson et al. 2016).

Autonomous vehicles promise a Cambrian explosion of new vehicle forms. Evidence for this is already emerging. Google/Waymo has proposed and built prototypes of a new, light, low speed neighborhood vehicle designed for slow speed (25 mph or 40 km/h) on campuses. The UK has four pilot programs starting.² Singapore is testing similar vehicles.³

This has important implications. For example, cars can be better

² (Topham 2015).

³ (Matheson 2016).

designed for specific purposes, since, if they are rented on-demand or shared, they don't need to be everything to their owner. Narrow and specialized cars like the Toyota iRoad (Figure 9.5) are more feasible in a world of autonomous vehicles. The fleet will have greater variety, with the right size vehicle assigned to a particular job. Today there is a car-size arms race, people buy larger cars, which are perceived to be safer for the occupant even if more hazardous for those around them, and taller cars, which allow the driver to see in front of the car immediately in front of them. Both of these advantages are largely obviated with autonomous vehicles. The car-size arms race ends.

The low mass of neighborhood and single-passenger vehicles like the Renault Twizy (Figure 9.6) will save energy and reduce pavement wear, but also cause less damage when it (inadvertently) hits something or someone. Combining the low mass with the lower likelihood of a crash at low speed will magnify its safety advantage for non-occupants in this environment, compared with faster, heavier vehicles, which privilege the safety of the vehicle occupants.

These savings will be passed on to consumers. Insurance companies will recognize the lower risks and lower rates. This will help drive adoption of autonomous vehicles. Alternatively, the auto-companies themselves may choose to accept liability for autonomous vehicles in autonomous mode, as some are already proposing.



Figure 9.6: Renault Twizy. Photo from Wikipedia

Dematerialization



Figure 10.1: Record player.
Source: Pexels.com (CCo
license)

Transport, as every textbook will tell you, is about the movement of people and goods. Communication is about the movement of ideas. To the extent people and goods have been moved to exchange ideas, the opportunity to dematerialize that transaction, and transform carriers of ideas from a physical (transportable) form to an electronic one emerges. This chapter investigates opportunities for dematerialization.

10.1 Dematerializing Music

In 1977, singer Shaun Cassidy took the cover of “Do you Believe in Magic” to a top 40 hit. The 45 rpm version of this song was the very first record Kevin bought from his hometown record shop in Glenview, Illinois. Such shops used to exist. They eventually gave

way to the national (mall-centric) chains (e.g., Sam Goody, Tower, Musicland), then big boxes like Best Buy and the booksellers started to get in on the act.

Thomas Edison first captured sounds as waveforms and recorded them as physical deviations (i.e., grooves) etched into a disc. The means of production, acquisition, and sound dissemination changed over the years. Physical reminders of this progression are apparent every time Kevin visits his parent's home. His grandparents' phonograph sits next to the turntable stereo (his mom's first purchase after she graduated from college in 1960), next to the compact disc player, next to the recent streaming device. The fact that all devices work, transmit sound, and are still used by his parents is more remarkable. Historically, these all required physically marrying two or more devices: the source, the instrument on which it is played, and the means of dissemination. Record players are largely gone, now trumped by modern forms of music playing (though admittedly, vinyl is coming back in vogue among hipster music fetishists). Stereo speakers are one-tenth the size of what both of us used in high school – long gone are those from Spinal Tap's famous brag: "these [speakers] go to 11!"

The technology of music changed faster than the book, moving from vinyl to tape (with the detour of 8-track tape) to CD to mp3 over two decades. In contrast with books, customers in large numbers digitized and shared their own music before the music industry could get their act together. Apple's iTunes was ultimately responsible for lowering digital music prices far enough that listening to music is again (maybe – who really knows?) more legal than illegal. Then, new distribution mechanisms changed the market again. Music is standardized, commodified, and the sequence in which one listens is customizable via internet radio services like Spotify and Pandora. Influential artists can hold the upper hand with respect to availability,¹ but songs are ubiquitous.

10.2 Dematerializing Books

Books – with the advent of online retailing (Amazon) – took a similar turn. In contrast with the home grown digitization of music, Amazon eventually took the next step and started to completely dematerialize books, by demanding eBooks from publishers, so that the entire product could be delivered over the Internet. In contrast, while there is copyright-violating sharing of eBooks, it is not the same order of magnitude as music.

Consider the purchase of something as straightforward as a book

Prior to the availability of 'the cloud,' bits of information were made available in different physical locations (not unlike records or tapes or CDs, but much moreso). Most commonly, this meant inserting a floppy disk (or connecting a hard drive) into one computer, transferring data, and then ejecting that disk and physically moving the information storage device to another computer. Sneaker-net (a play on Ethernet, except a human wore sneakers to physically move stored data) is the term to refer to the process by which files were transferred before broadband became widespread. Big data producers (e.g., Google) continue to rely on Fed Ex to move large data more quickly than the internet can. Depending on the size of the data file and the capacity of the digital networks, it may still be a preferred means of exchange. That too will one-day end. See also: (Munroe 2012).

¹ e.g., Taylor Swift banning her music from Spotify and others, and affecting the policy of Apple Music regarding artist compensation.

– a product that has only recently endured considerable change since Gutenberg’s 15th century invention of the printing press.

- I visit a monastery. I provide the monk a sack of coins and a goat in exchange for transcribing a book. I return home. Months later, I get a book.
- I go to a physical store. I provide the clerk a \$10 bill in exchange for a book. I return home.
- I go to the store and purchase a virtual good such as a gift card, paying for it with a debit card which I just tap on an electronic card reader. I return home, scan the gift card with a camera built into my computer. The virtual good (e.g., book) is available to me, via several formats.
- I go online and request a book from an online retailer’s database. I provide an electronic string of numbers ascribed to my credit card (which is already stored). Upon receipt, the database communicates with a warehouse, which dispatches a physical book on a physical vehicle down a physical right-of-way and delivers to my home.
- Via TouchID, (or FaceID) I order a book on my iPhone. Upon receipt, the Amazon database dispatches an eBook through the Internet, which after traversing fiber optic wires and local WiFi, automatically appears on the Kindle book-reading app on my phone.

Search for your favorite book followed by PDF, you might be surprised to find it on a non-US website). While searching the internet, David discovered a Russian pirate copy library site, which had lots of books available for download, including *The Transportation Experience*, which David wrote with Bill Garrison.

Two points come to mind:

1. Hey, cool, my work is worth pirating, and
2. Is it illegal *for me* to download this? (It is probably illegal for you to download it (unless you work at Oxford University Press), but the real crime would be if you uploaded it). It is obviously not immoral to download a book I wrote and have copies of, even if I did license Oxford University Press to publish it. Could I be prosecuted for downloading a copy of my own work?

Is downloading a book that I already own a paper copy of illegal? (Yes, probably.) Is scanning it? (Maybe.) Is there a difference?

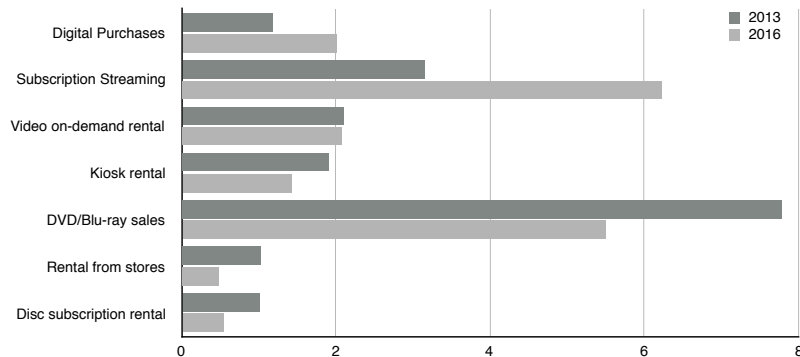
10.3 Dematerializing Movies

Analogous processes have transformed video. The acquisition of movies has even more options.

- I go to the movie theater, wait in line to buy tickets and sit down in the theater to watch the movie.
- I buy my tickets in advance on-line via Fandango (to free myself of worry about a sold-out theater) and whisk myself to a seat,
- I go to a video rental store – or more likely a RedBox DVD rental kiosk – rent a piece of plastic to put into a specialized player connected to a large monitor, and return it.
- I go to a Flix on Stix movie download kiosk, insert my own USB, rent some bits to put into a computer, which expire after I watch it.

- I watch a movie at a scheduled time on an ‘over-the-air’ or cable TV network
- I download a film on my tablet or TV (rented for a 24 hour period or bought to own) and watch it on my own schedule.
- I stream a film on-demand from a subscription service (e.g., Netflix).
- I find a magnet file, pointing me to a torrent file of a video stored in pieces across the Internet on many different peer computers, download the video which is, transcode it to a standard format, and watch it on my computer or stream to my TV via an app like Plex.

Figure 10.2: US home entertainment revenue 2013-2016 (\$B). Source: 2013 data from: (Fritz 2014) 2016 data from (Digital Entertainment Group 2017).



Electronic delivery is easily automated for bit-based goods like books, music, video, and software; it is in the active process of being transformed from shop-based selling to screen-based, as shown in Figure 10.2. By 2013 the legal video market was split between declining physical and rising electronic delivery. This does not even consider the unknown amount of illegal video traffic (such as BitTorrent), nor the fact that some legal downloads (like Netflix) show many more hours of video per dollar spent than legal rentals. Eventually (and not too far away) about 100% of this genre of product will be acquired online. In 2016 the US Video Game market was about \$12.1B for comparison, a similar magnitude, and down from \$19B in 2010.²

² Game data from (Statista 2017).

10.4 Dematerializing Architecture

Architecture in one sense deals with the most material of human creations, structures. Buildings are physical entities in the realm of

atoms as much as bits. The physical layout of buildings, their mass, structural elements, and so on are the work of architects. But there is another aspect of architecture which is primarily aesthetic. The surface form of structures, the gargoyles appended to buildings. This art lies firmly in the realm of information, even though it has historically been presented in concrete, wood, and masonry, rather than on paper, vinyl, or plastic.

The advent of augmented reality (AR) will allow us to dematerialize this aesthetic aspect of architecture. Instead of seeing the building as the architect designed it, we can see it according to our preference, with the skin we wish to attach. In a world of augmented reality, no one will pay for any ephemerally fashionable aesthetic attachments when they can subscribe to a set of aesthetics in software.

The form will still matter, as we still need to be inside buildings to stay dry, and need to know where the entrances and exits are to avoid walking into walls. Buildings as housers of beds and containers of furniture and tools will remain important, as will their spatial location. But ornament will decline in importance, as that will be in the eye (or the AR glasses) of the beholder. We can expect the emergence of new construction based on the plainest surface which will be the easiest to adapt to computer models.

In this, admittedly speculative, world, we will no longer need worry about historic preservation, bridges with egregious sight lines, or other offenses to our sensibilities. We will simply look through a heads-up display, or don the appropriate glasses or goggles (or farther into the future, jack our brains into the appropriate computers), and find ourselves presented with the world as we wish it to be.

This implies people will be less place-attached, and favors the Out scenario of Chapter 13.

10.5 *Materializing Information*

Producing three dimensional solid objects from a digital file (3D printing) is clearly in its infancy, but it is here.³ Alternative 3D printing scenarios are currently playing out with varying implications, depending on the context.⁴ As 3D printers improve more goods will be manufactured closer to their point of final consumption. Freight shipments will still occur, and the dry weight will be similar, in that the material used in the printing is still shipped as a raw commodity, though the water will be added later, similar to freeze dried camping meals or Coca-Cola from a fountain.

³ (Hart 2012).

⁴ (Birtchnell 2012).

Overall volumes will be much smaller as water, air, and packaging will not need to be shipped for as long a distance.

The nearest scenario centers on prototyping only. 3D printers already are used for this purpose, but who gets to prototype, or design, consumer products might be turned on its head as serious, enthusiastic consumers (prosumers) show manufacturers what they want, even if they don't have the materials to build a working version.

⁵ (Greenberg 2014).

A second scenario involves considerably advanced desktop printers in the home. People will design and share Intellectual Property (IP) – data files describing goods such as, cups, kitchenware, pens, guns.⁵ There are already several repositories of files to download. Subject to reverse engineering, pirated files might become the norm (following the well-worn path of music and videos). To the extent that personal travel is occupied with acquiring small, printable objects, travel will decrease.

A third scenario envisions a new industrial revolution focused on a new form of manufacturing. Smaller printing 'factories' will spring up across communities with the ability to make products. These may be private enterprises (new market opportunities will arise) or these resources may be provided in central locations. Libraries will continue to reinvent themselves away from the traditional reading-and-learning mission and transform into the digital age of providing a wider range of club goods that are under-provided to society thanks to transaction costs. Thus, libraries, together with community centers, might be the homes for community 3D printers. Mass customization will likely be a hallmark of these products but customized designs would shortly follow suit; altering designs will not require retooling, merely tweaking the code for the software. Large communities of 'modders' are likely. In this model, there is still a role for traditional freight (matter along physical networks) but based on much shorter distances, the 'last-mile' from the printer to the house.

The rise of online shopping for material goods detailed in Chapter 11 is a prime culprit in traffic's slow death. The dematerialization of information goods has also profoundly affected how the access to goods is conceived of and acquired.

⁶ See e.g. teledildonics.

The tactile is being substituted for, if not replaced, with the appropriate devices.⁶ The miniaturization of consumer goods has been ongoing for decades now (e.g., microwaves substituted for big ovens; portability also kicked in – master-blasters, boom boxes, Walkmans, laptops, tablets, and iPhones are all smaller than their predecessors)

10.6 The Matrix of Access

		Networks	
		Physical Networks	Digital Networks
Nouns	Things	[almost all focus has been here] Travel, Goods Delivery	3D printing
	Data	Mail, Books, Newspapers, CDs, DVDs	Streaming music or movies

Figure 10.3: We offer a Matrix of Accessibility to help redefine these fresh means of access and flows. We populate the box with some examples. We encourage the reader to think of others.

Some things that once required moving things can now be achieved by moving data. Subsequently, the ease and nature by which humans satisfy their desires is undergoing a revolution. Sure, people still transport themselves to do some things; they expect other things to come to them – digitally or not. Less important is how the transaction occurs.

But differences in the above exchange scenarios have notable transport implications. Roads have historically been the principal form of movement, for humans or things. But their utility is being overshadowed by data sent over digital networks. There are two foundational issues at play in these dynamics.

The first has to do with the *noun* being transported. Nouns may be things in the form of physical matter that one can feel, smell or touch. Alternatively, nouns might merely be data.⁷

The second is the transport network. Sometimes the means of transport is in the form of physical roads (in the traditional physical notion, the corridors that separate buildings and connect places across space). Data is often transmitted across digital networks by cables or radio waves, though a hard drive on a FedEx truck is also data in motion.

Classifying two types of nouns and two types of networks provides four cells to consider new models of accessibility, as in Table 10.3. Moving things (particularly humans) along physical rights of ways has been the staple of transport planning. For millennia, discussions focused on this first cell. Societies have built roads, expanded roads, built neighborhoods, expanded neighborhoods. Transport planning has been consumed with

⁷One could also think of data nouns as bits, the smallest unit of information that can be stored or manipulated on a computer, where eight bits equals a byte.

finding the best ways to connect matter moving along physical networks.

But it is now easier to conceptualize other forms of exchange. Or think of how instead of meeting in person, people transmit moving pictures of themselves in the form of data over digital networks, e.g., Skyping, FaceTime, or broadcasting live with Facebook Live or Periscope. While it is difficult to conceive of things moving over digital networks, the rise of 3D printing means data is being sent and instantly manufactured at physically remote locations. Ordering – and delivering – a pizza over the Internet, might be here sooner than later.⁸

⁸ Examples of 3D printing of pizzas or other food are (Prisco 2014; Opam 2014).

In Table 10.3 we offer a Matrix of Access to help redefine these fresh means of access and flows. We populate the box with some examples. We encourage the reader to think of others.

11

Delivery



Figure 11.1: The Balmain, New South Wales Post Office. Photo by David M. Levinson.

Chapter 13 alludes to ways in which changes in travel will change the built environment. People are changing how they spend their time and their frequency and purpose of travel. They are mixing physical and virtual travel in previously unseen ways. In this chapter we use *fetching* (or more formally shopping travel) and its substitute, *delivery*, as a lens through which to better understand how transport's demand from land use is also changing the land use in more nuanced ways than appear at first blush.¹

¹ We encourage the reader to think about transitions of other obsolete spaces, most notably offices.

11.1 *Stores and Shops*

"Shine that up and put \$7.50 on it... Shame to let a good toaster go to waste over a frayed cord." – Proposition Joe, *The Wire*.

In the American crime drama *The Wire*, Proposition Joe, a gang leader and drug dealer hangs out at his front, an appliance repair shop. Noting that it is in decline, in one episode he relays the quote we opened the chapter with. Given foreseeable changes in acquiring goods and services – alongside advances in freight distribution – a reasonable question revolves around the multi-purposed, changing nature, and future of place-based enterprises.

Prior to civilization, there was little trade and few 'stores.' People did not store much as they hunted or gathered the necessary provision of goods. With farming, surplus created stuff that required storage. Inventory was held. Trade emerged from the sale of surplus. When inventories were sold from fixed locations – in exchange for debt² and what ultimately became what is commonly recognized as money – retailing was born.

The idea of a store, where things that are desired by customers and stored by distributors, is ultimately one of sharing community resources.³ I may need tools or screws at some point, but rather than own all the tools or screws I might need, the neighborhood's hardware store is available to rent or sell things on a just-in-time basis. The outfit who owns the hardware store (an individual, a firm, a cooperative) is secondary to the necessity of such a function to achieve economies of scale and ensure variety. Lacking stores, everyone would need to inventory everything that was needed; they would need to truck and barter for goods with their makers, or exchange with neighbors and figure out who owned what, a much less efficient system.

Society needs both places to store items people may need in the future (and then acquire them when needed), and it needs shop-places to work on things, making them, repairing them, altering them. With the move toward a disposable society, where it costs less to make things than fix them,⁴ the relative share of space devoted to shops rather than stores has declined.

But given the need for shops and stores, how do you get to them, or do they come to you?

11.2 *Antecedents to the New Logistics*

The Post Office was once the center of community activity, and in Australia, post offices were among the grandest buildings of the

² (Graeber 2011).

³ A *shop* is simply the location where trade takes place or things are made or fixed. Implicitly, a *store* holds lots of things. This distinction is somewhat lost in modern use, 'shopping' and 'storing' have differing meanings. Yet there are still hardware stores and grocery stores (which are relatively large), but dress shops, tailor shops, auto repair shops (which at least the first two are relatively small, and the latter two refer to where things are made or transformed rather than pre-made things are sold).

⁴ After all, repair is a laborious process; there is only one way to make something, which can thus be automated, but an infinity of ways to break it.

Victorian era (Figure 11.1 shows a post office in Balmain, a suburb of Sydney). People would get mail twice a day from a mail carrier, and visit the post office frequently to mail letters or collect packages. In the US, the Post Office was thought so important for democracy, it was one of the few responsibilities set out in the US Constitution for the Federal Government. In Figure 3.12 we saw that mail delivery is falling, and attribute its decline to substitution by electronic forms. We further called out online shopping as one of the culprits in the decline of travel in Chapter 3.

The dot-com boom (lasting from 1997 to 2001) was all about the widespread leveraging of new forms of technology. Even then, companies like WebVan promised to deliver select goods within the same day; Kozmo claimed to do so within the same hour. Highly opportunistic investors and entrepreneurs were blinded by visions of early success. After the dot-com crash, markets invested in new technology ventures more cautiously.

Like video conferencing and automated cars, buying more things online is still an inevitable part of the future. But how soon? How much? In what ways? These continue to be outstanding questions.

It has been common for some years now to acquire some goods from the digital shopping world. Amazon stormed the market with books and dethroned the big box book sellers like Crown, Borders, and Barnes & Noble (who had earlier acquired and then shut many mall-based bookstores (Walden, B-Dalton), which had themselves pushed out many independent neighborhood bookstores). The reader now has access to far more content than just a decade ago. For the nostalgic, something has been lost as well. Such is progress, supposedly. Books were relatively easy kindling for this revolution, the ISBN code had been around in some form since 1965. While books can be dematerialized (Chapter 10), most goods cannot.

11.3 *The Informed Shopper*

Left unknown in all of this is the extent to which basic utilitarian shopping is transforming into entertainment and leisure. A likely cornerstone of place-based venues will revolve around retail establishments that amplify web-based purchases or cater to the impulse, artisan, or even tourist markets. Retailing is simultaneously undergoing an evolution – not quite the one leading to the replacement of the quintessential Main Street, but rather a necessary supplement, upgrade, and diversification into emerging forms of ‘click-and-mortar’ retail that integrate internet and traditional retail channels. The retail industry now talks about

e-commerce, m-commerce (mobile e-commerce), personalized products, reverse show-rooming (browsing online and purchasing in-store) and more. These synergistic strategies combine to form what is coined omni-channeling – availing of all channels to leverage the benefits of e-commerce (more information, product selection, convenience, speed, price comparison) with the drawing power of physical stores (e.g., sense of community personal relationship, easy returns, full sensory experience). A logical next step is intelligent consumerism. Amazon is seeking to patent pre-cognition, sending you what you are going to order before you order it.

A related layer is that consumers are getting smarter. Almost two-thirds of Americans have a smartphone and 80 percent of them are ‘smartphone shoppers,’ researching products and comparing prices while in a store.⁵ While 63% of people in the US made a purchase online in 2014, 80% of sales still occur in a physical store and e-commerce only accounts for about 6% of retail sales worldwide.⁶ Clicks still benefit from bricks. And though e-commerce is increasing its momentum, it has progressed slower than anticipated by some during the DotCom boom of the 1990s.⁷

⁵ (Grieder et al. 2014).

⁶ (eMarketer 2015).

⁷ (Pavitt 1997).

11.4 *Drive-thru*

Like many pedestrians and bicyclists, we are annoyed with the hostility the drive-thru poses to non-auto modes. David was reprimanded for walking up to a drive-thru ATM at a Maryland National Bank in Columbia (after many acquisitions, now part of Bank of America) ... of course there was no walk-up ATM there, or he would have used that. If he doesn’t want to, or can’t deal with a person, he still has to walk-up to the 1980s era drive-thru ATM at his Minneapolis Credit Union, which still does not have a proper walk-up ATM. The drive-thru ATM is the wrong height for standing customers and provides a poor user interface. The drive-thru is a cross-subsidy non-driving customers give to the driving customers, who pay no extra for the larger building and infrastructure they require.

Drive-thru businesses have a long history in the US, dating at least from 1930 in the banking sector. Obviously gas stations were drive-thru. McDonald’s gets 65 percent of US sales from drive-thru.⁸ and there are an estimated 100,000 drive-thru quick-serve (i.e. fast-food) restaurants in the US.⁹

⁸ (Vanderbilt 2009).

⁹ (Allain 2008).

Banks still use yesterday’s future mode of transport, the pneumatic tubes. It’s not just gas stations, banks, and restaurants,

we have seen:

- Drive-thru dairy store.
- Drive-thru film development stores (Fotomat) (now obsolete).
- Drive-thru liquor and gun store, everything for good-ole-boys to have a really good time on a Friday night.
- Drive-thru romance store in Alabama, which gives a different meaning to the term ‘quickie’.

The US may have saturated the drive-thru market. Whether delivery can make this go down even further is unclear. It is still speculative, and future data will be required to confirm this, but if so, we may be facing a more walk-up America.

11.5 *New Logistics*

Advances and changes in logistics distribution also are important. One can expect similar levels of murkiness from freight transport – a transition that will be influenced by enhanced graphical interfaces, 3-D printing, and changes in freight delivery. The less that is fetched, the more that is delivered. Stuff needs to get in the hands of consumers. While most people shun trucks and delivery vehicles, potato chips still need to get from the factory to the shelf of the food store or your home somehow, as the immaculate conception of deep fried crisps has yet to be discovered. The amount of freight moved by various modes plummeted during the recent recession. Now truck travel appears to be generally slowly on the rise (Figure 11.3), even at the per capita level, in the US.

The US currently has three major national networks (USPS, UPS, FedEx) that deliver stuff to consumers in ways that are cost effective for many goods. Specialty services are on top of this – local stores and restaurants that deliver their own products (furniture, appliances, grocers, newspapers, milk, pizza), and one can certainly imagine others emerging.

New delivery models are available and coming. For the ‘last mile’ connecting the home with the final distribution point, new models include:

- Lockers (akin to PO Boxes) where stuff can be deposited for you to collect,¹⁰
- Peer-to-peer delivery services (friends or strangers will pick up goods for you and deliver them to your home or workplace),

¹⁰ The Amazon acquisition of Whole Foods may in part be about this.

¹¹ (Rubin 2015).¹² (Huston 2016).

- Firms depositing goods directly in the trunk of your car while you work,¹¹
- Deliveries of small packages by drone or robot,¹² and
- Neighborhood refrigerators for grocery dropoff.

Google and others are trying to uncover a workable economic model for same-day delivery of many of these services. Amazon, the e-commerce giant is seeking permission from the Federal Aviation Administration to deliver goods less than five pounds (2.3 kg) via drones. Considering 86% of their inventory are goods less than five pounds, this in and of itself would be a game-changer for the delivery business. Fortunately, no one is yet seriously proposing catapult-based freight delivery. Even drones will create controversies. How high above a house can you prohibit unmanned aerial vehicles? How often will they be shot out of the sky in the land of the Second Amendment?

Today simple delivery – following the revolution in online ordering in the 1990s – is itself transforming. Customers in Manhattan can order a mattress this morning (via Casper), have it delivered this afternoon, and sleep on it this evening; if it fails to meet their standard, they can have it picked up tomorrow morning for a full refund. The same holds for eyeglasses (via Warby Parker) and apparel. It used to be important to lay on the mattress, or actually see how new eyeglasses looked on our face, though getting to the store to do so was an inconvenience.

¹³ (Bensinger 2014).

With Amazon's decision to rent a warehouse in Midtown Manhattan for the next 15 years,¹³ Manhattanites were introduced to guaranteed one-hour delivery which is doing away with such inconvenience. And now, via tiny plastic adhesives affixed to your dishwasher, coffee machine or refrigerator, you can order your favorite household products with the touch of a single, physical electronic button. Amazon places the order, sends an alert to your phone, and it arrives within 24 hours. AmazonFresh delivers groceries to your door same day or early morning. Amazon Prime Now offers delivery within an hour of selected goods in selected areas. Done. The dream of the DotCom bubble has been revived and realized, though whether it can be sustained remains unknown.

11.6 *Eating-in / Eating-out / Take-away / Delivery*

Trends are transforming retail from a functional and transactional activity into a service and entertainment one. Restaurants and bars seem poised to enter this void.

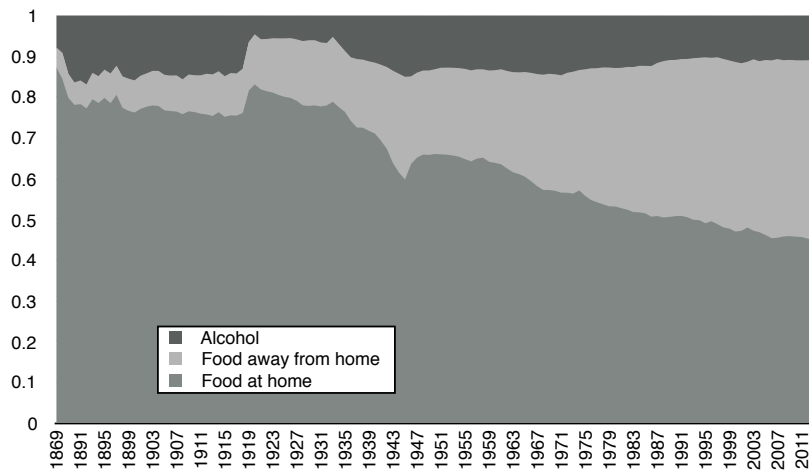


Figure 11.2: Food and alcohol expenditures (by share) 1869-2014. Source: (Economic Research Service 2017). This is largely attributed to both efficiencies in food production and higher incomes enabling more of it to be spent on more expensive options.

In contrast with reduced shopping, and perhaps because of it, the trends in eating differ from those of retail. Over more than a century, eating out has eaten a larger share of the food budget, as shown in Figure 11.2. Going to restaurants is an increasingly important social (and personal) activity, and in 2014 overtook food at home for the first time.

For the family seeking to eat at home but not prepare the food, urban dwellers have options. Some restaurants offer delivery as well as take-away, others offer take-away but don't deliver, and some specialize in delivery and avoid the storefront. For the customer who is not out and about, delivery is more convenient. For the customer who is passing by the restaurant anyway, ordering ahead and doing take-out¹⁴ wins out, since there is no waiting for the delivery, the additional distance is small, and tipping charges (or delivery surcharges) are avoided. Drive-thru (Section 11.4) is take-away for fast food, which avoids the pre-ordering step, arguably at the cost of food quality. There are now subscription services for dinner.

The blocks on which both David and Kevin currently live are comprised of mostly single family homes with some duplexes and apartments. Both neighborhoods once had two small grocery stores, founded before the days of cheap at home refrigeration and large grocery chains. These grocery stores are now gone. In David's neighborhood, one is now housing, the other a small restaurant.

Where these things are located relative to where people live and work depends on the frequency of use. People want vendors of things they desire more frequently (e.g., milk, coffee) to be closer

¹⁴ Take-out is often called take-away or carry-out or parcel in different localized variants of English.

than things desired less frequently (e.g. furniture). But closer and farther are relative, not absolute terms. They depend on context: location with respect to others (density or community demand), the cost of travel (technology), frequency of use (individual demand), and so on. Relative locations have changed over time as density, technology, and demand have changed.

¹⁵ (Mignot 2015).

¹⁶ (Fowler 2015).

In the mid 2010s, food and grocery delivery has turned into a hot sector receiving huge investments from venture capital.¹⁵ As the Wall Street Journal says “There’s an Uber for Everything: Apps do your chores: shopping, parking, cooking, cleaning, packing, shipping and more.”¹⁶ The article cites startups (mostly Bay Area) with apps that dispatch someone for flower delivery (BloomThat), delivering anything in town (Postmates), package pickup (Shyp), healthy meals (Sprig, SpoonRocket, Munchery), less healthy meals (Push for Pizza), washing your clothes (Washio (*now Rinse*)), washing your car (Cherry), parking your car valet-style (Luxe), packing your suitcase (Dufl), babysitting (UrbanSitter), dog sitting (Rover), medical house calls (Heal), self-medicating alcohol (Saucey), medicinal delivery (pot) (Eaze), and in-home massage (Zeel). Sadly, we don’t expect most of these (or their customers) will survive the revolution. (*Update for Second Edition: SpoonRocket and Cherry are no longer with us.*)¹⁷

¹⁷ There was once a Twitter account [[@uber_but_for](#)] mocking such services that auto-retweets posts that say things “like Uber for ...”.

Australia, among other places, is crawling with restaurant delivery companies (e.g. Foodora, MenuLog, Deliveroo, UberEATS, The Fork, Delivery Hero). Fresh ingredients in meal kits so you can cook yourself (Hello Fresh, Plated, Blue Apron, Home Chef, Purple Carrot, and Peach Dish) are also rising in popularity for people with too much money or not enough time, though these tend not be as on-demand. Hot lunch delivery is common in China and India, facilitated by smartphones. Instead of 100 people at an organization going out to lunch, 10 couriers deliver food, decimating trip-making. There are lots of ‘Uber fors ...’ in the transport sector. Replacing many activities by delivery will create demands for new and different out-of-home activities.

In the 1980s people mocked the idea of ordering a pizza from a (very large) ‘car-phone’ and then having it delivered to you in your car while moving. Today, pizzas are routinely ordered from mobile phones or apps, often sparing the need to talk to a clerk with the associated mis-order. Still, while airplanes can refuel in mid-air, the consumerist nirvana of synchronized in-motion pizza delivery has yet to be realized outside of television ads.

This also evokes the famous Grey Poupon television ads from 1991, featuring two famous television prime ministers, Jim Hacker (played by Paul Eddington) from *Yes, Prime Minister* and Francis Urquhart (played by Ian Richardson), from the original *House of Cards*. Hacker is enjoying his mustard in the back of his Rolls-Royce, and Urquhart pulls up in another Rolls, and asks “Pardon me, would you have some Grey Poupon?” To which Hacker replies “But of course”, and, in some versions of the ad, drives away. All of which is just anticipation of ad-hoc, real-time, peer-to-peer delivery, or an ‘Uber for Mustard,’ if you will.

11.7 *The Digital Battleground*

Anything that is standardized and commodified, and whose delivery is easily automated is prime ground for the new logistics. All of these deliveries reduce travel to the store, while increasing travel in the logistics supply chain, but generally reduce travel overall.

How far will it go and how fast is informed by preferences for ensuring quality. Kevin recently built a treehouse for his son; he could have had 2x4s delivered, which would likely have been crooked with many imperfections; alternatively, he could have gone to the lumber store and selected ‘good’ ones himself. Preferences for lifestyle (how much time, on average, will people want to spend inside versus outside the home), technology (how quickly can the product arrive), and countless other factors also shape choice of in-person shopping vs. delivery.

On the other end of the spectrum are goods like fresh food that people like to inspect or touch before purchasing. Culture plays a role. Having lived for a year in Italy, Kevin knows few (if any) self-respecting Italians who would conceive of having an unknown person select tomatoes on their behalf – fish and meat products are not far off. Americans, on the other hand, have relegated themselves to commoditized food products, even tomatoes.¹⁸

¹⁸ We are told that in Los Angeles, there are snooty vegetable delivery services.

In between these two extremes is what analysts term a ‘digital battleground.’ This domain includes home decor, office supplies, clothing, footwear and all the rest (mattresses, eyeglasses, sweaters, souvenir items). Left to be determined by the market are thresholds for when particular goods transition to e-commerce for any given consumer.

There remains a long-tail of desired, but still standard, goods that one cannot find at the corner store because it lacks the space to inventory everything. Many goods are easy to ship (and even easier to ship in electronic versions). Other goods – all commodified though not digitized – would be amenable to new distribution systems, which can all be ordered and delivered within 48 hours (if not sooner). Even custom goods get sold on places like Etsy. While used (and new) items both standard and non-standard are offered on Ebay.

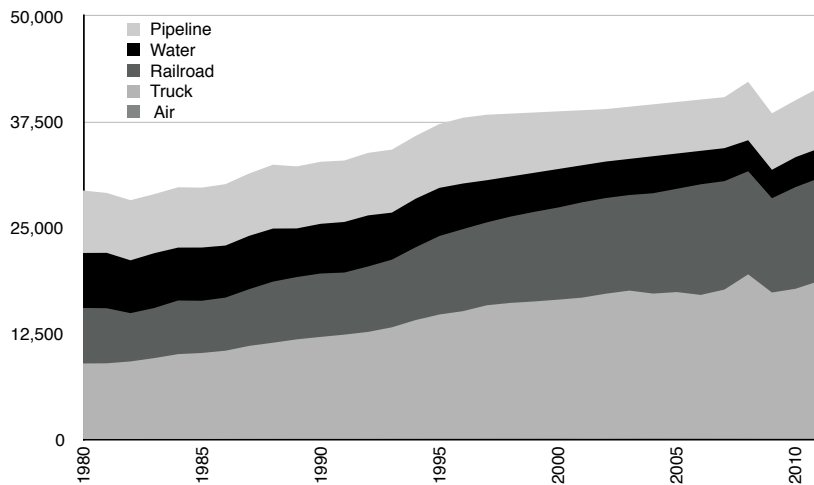
Pressing an Amazon Dash button that is placed in your home that is emblazoned with a product logo, sends a Wi-Fi signal to the Amazon Shopping app. The signal would automatically order new stock of whatever product the button is configured to order; the click would also send a message to the user’s mobile phone, and the user would have a half-hour window to cancel. This might be ideal for

commodities like detergent.

The future of shopping will fall along a continuum of commodified versus uncommodified products. Sometimes it is the overall experience of ‘shopping,’ regardless of the product, that people seek. Stores are revolutionizing the physical shopping experience – as an entertainment option of sorts. While online shopping will continue to grow, we doubt it will reach anywhere near 100% anytime soon. Where shopping is a chore, online shopping and automated ordering will replace it. When shopping is a pleasure, it won’t.

11.8 Will Freight Rise?

Figure 11.3: US ton-km of domestic freight by mode (per capita) 1980-2011. Source: (Bureau of Transportation Statistics 2017) Table 1-50: US Ton-Miles of Freight (Millions).



The USDOT’s *Beyond Traffic* report says that though the population of the US will increase by 70 million people by 2040 (about 22%) and freight will increase by 45%. Why should freight rise twice as fast over this period?¹⁹

¹⁹ (US Department of Transportation 2016).

Certainly there is a rise in teleshopping, so local logistics will increase. Currently e-shopping is on the order of (and likely under) 10% of retail sales, but it is growing. Shopping is less than 10% of personal travel.

There are several aspects to logistics. There is the shipment from factory to distribution center, from one distribution center to another, and from the final distribution center to the final destination (usually home), the last mile. If the total goods consumed remain the same, the first two stages are essentially unchanged.

If the freight delivery system currently covers every street (that is

the UPS guy comes down your street once a day, every day), it will continue to cover every street, just with more vehicles dispatched from the dispatch center to the last mile(s), as with more deliveries there will be more trucks dispatched and each truck will have a shorter, but more intensive route. Ignoring automation in this field (and surely there will be some), once the appropriate optimizations are made in terms of grouping shipments, this still has to be more efficient than individuals going out and coming back from shopping trips, but may net out as more freight travel and less personal travel.

We might also see a delivery system covering every street twice a day, or four times a day, as real-time deliveries become more significant. It is a large bet by Amazon that Prime Now – type services will be a thing for most people most of the time (testing the assumption that most people can wait for their lightbulb if it saves some money), but nevertheless if those trucks are not optimally filled, it would increase total freight travel.

There is then the question of whether more material will be consumed overall. We expect total matter shipped should decline on a per capita basis. By the time period in question, 2040, the US should be off of coal and oil, replaced with renewable electricity (whose transmission does not count as transportation, unlike coal, oil, or gas). This will devastate the railroad industry, which will then try to use its surplus capacity to move into markets now served by trucks.

Further think about things you use. Many of them are smaller than their equivalent 25 years ago (phones, TVs, computers, cars). Now we may have more of them, or they may have different shapes (TVs have more screen and less depth with the loss of the Cathode Ray Tube) and we might need more furniture to occupy our large houses, but that is relatively small in the scheme of things, most freight are things which are consumed daily (food products, energy), not long term capital goods.

We might also increase freight travel if we increase the distances that freight is shipped, but keep the quantity the same. Can supply chains become even more global? Will they? With automation, the advantages of cheap labor in the production system will diminish, and it will be easier to manufacture locally (to reduce transportation costs and make just-in-time more viable). With cheap energy, things that are now difficult and expensive (like growing exotic fruits and vegetables indoors) will become more viable.

The net is uncertain, we cannot know whether freight shipments will grow faster or slower than population, but the claim of a 45% increase is an assumption that should be pushed back on. It is used

to justify government investments in highways (and ports and railroads to a lesser extent) for freight which can no longer be justified based on rising per capita passenger travel.

11.9 *Deconsumption*

The rise of delivery does not imply less consumption, but they are related. The decline of shopping travel is one aspect (both a cause and effect) of the decline of personal travel overall, and has many knock-on effects. Cities need fewer roads to get to stores and shops. Centers warrant less parking. Today residents need fewer stores and shopping centers since they inventory more in their large homes with second freezers. Delivery might entail different economies of scale than fetching from the store, as people can get what they want when they need, just-in-time consumption. Travelers might engage in other out-of-home activities, especially eating, to substitute for shopping as 'entertainment,' but it won't fully substitute.

Similarly, the same underlying trends portend a decline in work travel, as workers take some of the gains of automation and information technology with less time in the office or the factory (or hospital, or school, or any of the thousands of other worksites).

Eventually there may be replicators, or pneumatic tubes, or aerial drones, or good 3-D printers, and delivery as most people think of it now will also decline. Or, there may be less overall consumption. But we can fairly safely extrapolate that, for a while, 20th century retail infrastructure and supporting transport system of roads and parking is overbuilt for the 21st century last-mile delivery problems in an era with growing internet shopping.

12

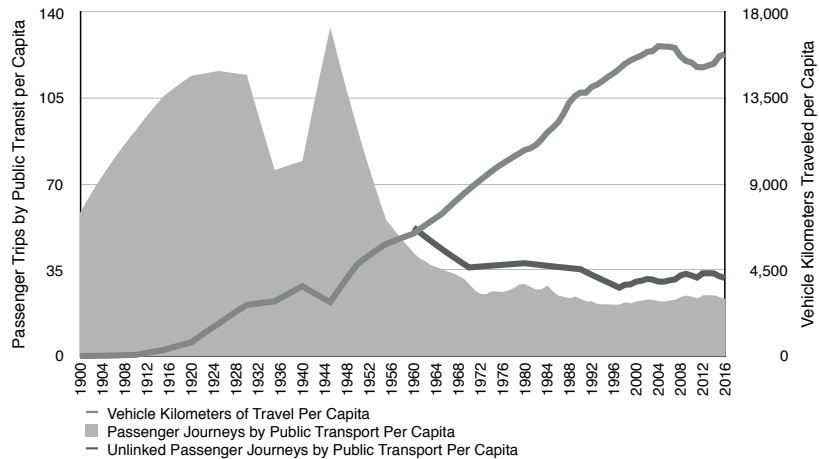
Transit



Figure 12.1: Clouds, valleys, and mountain peaks. Photo by Kevin J. Krizek.

From the 1880s through the early 1920s, transport explorers in the US spent their time climbing Mount Transit. It was not until the mid 1920s that they switched routes to ascend Mount Auto. At the turn of the century, transit was the most important mode of travel (after walking) in large and medium-sized US cities. Transit's ascent was enabled by the electric streetcar, first deployed in Richmond, Virginia in 1887 by Frank Sprague. It's widespread distribution was as a product of electricity harnessed by Thomas Edison, Nikolai Tesla, George Westinghouse and others, and the modern railroad, developed beginning in 1825 with George Stephenson's steam-powered Stockton and Darlington Railway. The transport climbers in the US came upon false summit of Mt. Transit in the

Figure 12.2: Descending Mount Transit. Note: The graph shows both linked and unlinked transit trips, as the way transit trips are counted has changed, and there is no continuous series of both over the entire period. We estimated linked transit trips to improve clarity of presentation, but these are unofficial estimates. Source: (US Census Bureau 1992; Highway Statistics 2016).



1920s; the real one was discovered two decades later with transit's peak during World War II when oil and rubber were rationed, crimping the automobile's use, shown in Figure 12.2.

Transit is hardly a new idea. The endpoints of the spectrum for non-human powered mobility have remained static for a long time. On one end lies small capsules carrying single individuals to geographically dispersed destinations (e.g., cars – human driven or not – or bikes). At the other end lies larger capsules carrying many individuals to geographically concentrated destinations (i.e., mass transit). The space between these end-posts has historically been barren, leading some to refer to the 'goldilocks problem.'¹ But both the characteristics of the endpoints and the in-between points of this spectrum are rapidly changing.

Cars, as people have come to know them, will soon share a few advantages that have traditionally been afforded only to traditional mass transit such as the ability to work while traveling (multitask). Then, modified (and likely shorter) versions of the 40-foot bus will start acting more like cars. Those modes which have historically been distinct and separate are morphing as new modes emerge to fill the space between. Most future of technology discussions thus far have focused on the role of the Internet or energy. Advances in vehicle technology forms a perfect third.

Many dimensions differentiate transport modes.² Key elements include the degree of personal control of *personal space*,³ freedom and *flexibility of schedule*, and *proximity* of the vehicle boarding and alighting location to actual origin or destination (convenience). In this chapter we differentiate macro-transit from micro-transit.

¹ See: (Nisenson 2015).

² See Taxonomy of Modes in *Elements of Access* (Levinson et al. 2018).

³ Car seats that fit your children is another factor of personal space that favors ownership.

12.1 Macro-Transit

A feature that distinguishes the far end of the spectrum of (non-human powered) mobility lies in the onset of a fixed route. These systems usually come in the form of grade-separated metros (as found in roughly 150 cities across the globe), tram systems, exclusive busways, and high frequency all-day commuter train service.

Differences are notable and important, but most elements about these macro systems are *high*. High costs invoke high stakes; they require high development intensity (to be successful) and high frequency of service with high capacity to invoke high ridership to pay for them. When these systems are appropriately placed within the urban fabric, they do wonders for mobility. These systems will retain their prominent role in large central cities.

But many questions and challenges also surround macro-transit systems – issues which vary for existing versus future systems – which differ from system extensions. Rail transit is rigid. Recognizing that rail can help influence development patterns, fixed rail’s lack of flexibility limits its ability to adapt to uncertain futures. In the absence of new cost-saving tunneling technologies and changes to environmental and planning review regulations, *rail will not have the ability to quickly and suitably address transport problems in emerging corridors*.

To some advocates, inflexibility is an asset rather than a liability. Rail cannot be easily repurposed to other modes in the same way an HOV lane or Busway could easily be repurposed for cars. However, it was the inflexibility of the streetcars that led to their removal, and the lanes were repurposed anyway; and it is not like transit service itself disappeared, corridors with enough demand for streetcars obtained bus service.

The use of fixed rail to spur development in the modern era has usually been disappointing, as US cities are mature and indifferent to marginal changes. Los Angeles’s massive \$22 Billion investment in rail transit has served many riders, but lost market share overall. Despite spending nearly a quarter of federal surface transportation dollars on public transportation investments over the past four decades, transit work trip mode share has fallen nationally from 9 percent in 1970 to 5 percent of all work trips in 2012. In short, public expenditure per transit user far exceeds public expenditure per highway user, and has failed to significantly reverse long-term trends.

Fixed-rail transit is far less flexible than bus (or micro and

Like anything, different surveys with different assumptions produce different transit mode shares. For a comparison see (Polzin and Chu 2005). Current numbers are reported by (Bureau of Transportation Statistics 2017) Table 1-41 “Principal Means of Transportation to Work.” Expenditure data can be found in Table 3-35 “Transportation Expenditures by Mode and Level of Government from Own Funds, Fiscal Year”.

traditional bus transit, MaaS, or the automobile) and thus far *less attractive* when not traveling to downtown or other high demand locations. The key decision is whether to build it. Once present, it is stuck there and few such systems are abandoned after opening. As economists would appropriately say about subway systems, “sunk costs are sunk,” meaning one cannot worry about whether the fixed costs were worthwhile after we embed the capital into the ground. Society has paid for it in any case, and the relevant question is whether it is worth paying for continued operations.

LAND USE. The critical issue dictating the success of these systems lies in the land use conditions surrounding the stations. *Put simply, ‘mass transit’ needs masses of people.*⁴ There is a market demand for higher density living, just look at the recent building boom in urban centers from Seattle to Minneapolis.

It is worth noting that much of the urban building boom of six story apartment buildings is due to recent changes in construction standards (such as the International Building Code in 2000) responding to improved wood building materials and allowing woodframe construction (which had been prohibited due to fire concerns).⁵

There remains market demand for lower density living, the suburbs keep rolling along and still get the most growth. The future success of transit depends of the size of urban area.

Given most of the best routes have already been built in places like New York and Chicago, new fixed route transit systems will be heading toward markets with both less development intensity and less potential. Diminishing returns have already set in; but that does not necessarily mean there are no worthwhile investments. If the demand for more intensive land uses (bigger and taller buildings covering a larger share of the ground) rises, the big question will revolve around reconciling tensions between attracting more ridership versus construction costs. Higher densities increase both ridership and construction cost.⁶ But one thing will be clear. With increased diversity of options that are developing along the other end of the mobility spectrum, fixed route systems will not have the ability to successfully address locations without relatively high density. More on Land Use is discussed in Chapter 13.

⁴ Looking at 59 transit projects showed that a 10 percent increase in total population per acre corresponded with a 3.2 percent drop in capital costs per rider. The same 10 percent increase in jobs per acre resulted in per-rider capital costs falling 1.5 percent. See: (Guerra and Cervero 2011).

⁵ See e.g. (Lewington 2014).

ACCESS AND EGRESS. *With the onset of autonomous vehicles, MaaS, and new forms of micro-transit – together with walking and cycling (both conventional and e-bikes) – the current barriers of access and egress to these systems will be lowered.* With autonomous vehicles, the whole

concept of park-and-rides and dealing with parking around stations (presently a large enabler of patronage at suburban rail stations) enter the dustbin of history, since the cars can either drive farther away to park, or better, serve other travelers. MaaS transport and micro-transit services will be readily available.

RELIABILITY. Certainty is important, but it is quite possible for transit to become certainly unreliable. Improving the reliability of transit services is another step to increasing ridership. Transit signal pre-emption and priority are two technologies that help keep on-road transit moving, providing a leg-up to macro-transit bus rapid transit systems, vans, and other micro-transit services. Transit engineers like to talk about others: locating stops so that transit vehicles stay in the lane (admittedly blocking cars), and don't have a merge manoeuvre; boarding via all doors simultaneously; and speeding boarding times with all passengers having prepaid, it turns out most time is lost in payment. This is no longer high-technology, but it is application of technology in a way that is uncommon in the US (though widespread in so-called 'developing' countries like China, Brazil, and Colombia, which are far-superior in their public transit than the supposedly 'developed' US). *Reducing uncertainty is certainly a key characteristic for the success of any transport mode's ability to attract users.*⁷

NEW VERSUS OLD. So called 'legacy' metro systems in the US account for over half the nation's fixed-rail transit passengers (especially Boston, Chicago, New York, Philadelphia, San Francisco MUNI). Middle-aged US systems born in the 1970s like San Francisco's BART, Baltimore and Washington DC's Metros, and Atlanta's MARTA now face issues associated with aging infrastructure, brittle labor relations, and fixed networks unable to meet changing demand patterns.

The challenges facing older systems differ from those that were first launched after 1980 in the era of Light Rail. *Expanding and extending existing networks is immensely easier (sclerotic New York excepted), and given network effects, more promising than starting from scratch.* New and emerging systems (at least in the US) are sold on their ability to yield under-appreciated environmental and societal benefits. Where there are large volumes of people already moving in key corridors, the leap to fixed route service is inevitable. But elsewhere, the assumption is precarious because MaaS transport and micro-transit will suitably serve these markets.

⁷It is a common observation in the travel demand modeling community that waiting time is at least twice as onerous as in-vehicle time. Why should that be? One of the main problems with waiting is uncertainty about when transit vehicles will arrive. Real-time information is now becoming widespread, so with the touch of a finger on a smartphone or watch, one can know down to the minute when the next vehicle will arrive, can have suggested routes, and soon with that same smart device, pay in advance or with a tap while boarding the vehicle. It is expected that as certainty comes into the system, the perceived time of transit trips will drop, which should attract more users.

PRICING. The rationale behind pricing structures across existing transit systems, however, has as much predictability as the lines and location of the paint in Jackson Pollack's artwork. Pricing schemes may be distance based, trip based, or transfer based; others are policy choices based on tradition and inertia. In most macro-transit systems, fares cover less than half of operating costs and none of the capital costs.⁸ *Raising fares to cover operations with separate subsidies for those who need them is a likely direction.* This requires auto travel to be appropriately priced as well.

⁸ The farebox recovery ratio, the share of operating expenditures covered by fares, nationally was 33.4% in 2003 and 32.8% in 2012. (Office of Budget and Policy 2013).

PAYMENT. Adopting payment systems that seamlessly integrate with all other forms of transport, and the rest of life, is an integral step forward. *While smart cards are better than ticketing and tokens, transit doesn't require its own currency.* Integrated and multi-modal smart payment systems based off of location-aware smart devices will be available, reducing the headaches of ticketing.

The bus was a frequent source of mobility while Kevin lived in Bologna (Italy). For those without monthly passes, the process was relatively simple. You would buy tickets at the local newspaper stand or the *tabbaccaria* or some other local shops. Otherwise, you could purchase a ticket from the machine on-board (in many European models of bus transport, the driver does not handle money nor does he interact with the passengers). The system was straightforward. That is, unless the newspaper stand was on-strike from selling tickets, and the *tabbaccaria* had no more tickets to sell, and the other shops were closed, and the ticket machine on the bus was not functioning. The only option was the ride the bus sans ticket – and this culmination of events occurred surprisingly, and unpredictably, often. And, of course, by riding the bus without a ticket prompts the undercover transit police to issue an 80 euro penalty. This happened to Kevin once.

An app on your phone, watch, or other device, or even a biometric account linked to a thumbprint or eyeball scan, will connect with the station or vehicle once you board, and when you alight, automatically debit your account. In exchange, the agency knows that you are on-board and where you are sitting. This information is potentially valuable to advertisers, helping defray costs. Removing the payment delay as people board vehicles is just the first stage.

MEMBERSHIP. Most transport systems worldwide currently charge on a per use basis, either by cash or with a stored-value card. Many allow a season pass for unlimited use.⁹ But so far, this is just a

⁹ For the individual traveler, a season pass is worthwhile at current fares if you are essentially a daily user for commute trips, or use it for a lot of non-commute trips as well. In the Twin Cities 9.5 million rides of a total of ~71 million (which depends on what numbers you use) on Metro Transit use MetroPass. "Unlimited" use still has limits, for instance in the Twin Cities you still need to pay for services > \$3 per ride, i.e. Northstar Commuter Rail line.

payment mechanism, not a change in how the passengers view the system or the system views the passenger.

Consider payment differences for holders of season passes vs. pay-as-you-ride. There are probably a lot of existing riders who would benefit from a pass who don't get one. Possessing a pass would induce the rider to make more trips by transit (since the marginal cost of use would now be zero). At a relatively lower price, more people would get a pass. We would expect more people to have passes than use the passes on the system every day (not every pass-holder need be a daily rider). People pay for the option without having to think about price, offering several benefits. Loyalty programs are a related strategy, now employed by airlines, to keep customers coming back.¹⁰

Now couple the season pass with a change in system organization. Season-pass holders are members. *Membership changes the perspective from being a customer to being a long-term stake-holder and owner of the system.* As a member of a club, I want there to be more members, as it helps spread the costs and raises money for the services provided. I become an advocate for the organizations I join. If executed well, I may even feel part of a larger social whole (though we expect few identify with their car rental service like Hertz or Avis). I help maintain it, since it is my property. Psychologically speaking, users act differently when they feel they have meaningful input into decisions, thereby affecting outcomes.

AUTOMATION. It is surprising that, in 2015 in the US, outside of airports, most modern, grade-separated rail systems fail to all have automatic train operation (ATO). Administering organizations might still be licking their wounds from previous mishaps.

Two mishaps stand out:

1. Bay Area Rapid Transit: Fremont Flyer crash (October 2, 1972) – a train under testing with automatic control overshot the end of the track;¹¹
2. The Dockland Light Railway (March 10, 1987) test case failed to stop at the terminus.¹²

In one case (San Francisco's BART), drivers were re-inserted into the system, in the other (London's Dockland Light Rail), driverless trains remained standard (and safe).

Eventually, trains and buses will be routinely driverless. However, given the general technological torpor, and institutional rigidity, along with public union strength, in the macro-transit sector, this is likely decades away from full deployment.

¹⁰ Some cities have Bus Riders Unions, but they are often at odds with the transit agency. Almost everywhere has an Automobile Association (Minneapolis and St. Paul each have one), about which I may have warm feelings since they help start my car when the battery is dead, or change a tire, or tow it when something else breaks. Transit workers are members of their workers union. Even transit agencies are members of APTA trade association. We cannot find an example of a transit system that organizes and treats its riders as members. We believe this will change.

Why shouldn't riders be members of the non-profit organization that provides them transportation services on a regular basis? And why shouldn't they help govern that organization? And why shouldn't there be more than one so that they can both compete and coordinate to better serve travelers?

¹¹ (Middleton 2003).

¹² (London Reconnections 2013).

12.2 *Micro-Transit*

Bridging the gap between single user transport owned either individually (car) or delivered as part of a service (MaaS Transport) and fixed-route public transit (Macro-Transit) lies a rapidly emerging form of mobility dubbed ‘micro-transit.’ Users share their slightly larger capsule (a vehicle larger than a car but smaller than a large bus or train) with others.

This ‘great middle’ is being contested by vehicles of various sizes and shapes. While currently driven by humans, they will eventually be led by machines that dynamically match vehicles, passengers, and destinations in a way that is cost-effective and attractive to consumers. Operating on everyday streets and accessing relatively low-density destinations, access and egress distances for these systems are less than fixed route transit. But here, increased flexibility can be purchased; small distances can be eliminated by paying more. Micro-transit exists in a variety of small forms today, as described below. But it can ramp up by applying real-time information and mobile communications. Notably, conventional micro-transit typically focuses on work trips, while the newer MaaS systems are primarily for anything but commuting. Intercity trips have their own and separate dynamics.¹³

¹³ Firms like Megabus and Bolt serve the intercity market in a way with lower prices and WiFi that appeals to passengers more than Greyhound or Amtrak. Yet these kinds of services cannot work point-to-point in *all* markets. Most pairs of origins and destinations are too small. But that does not mean they cannot work in *any* market. Finding the customers best served by any new technology, such as this new information-powered bus-sized vehicles is what market economies are best at. (Schwieterman et al. 2007; Fischer and Schwieterman 2011).

VANPOOL. Micro-transit is on a continuum from the automobile and MaaS. This is best illustrated at the most basic level, the vanpool, which gained popularity with the oil shocks of the 1970s. Ranging from a scaled-up carpool where riders chip in to pay the driver/owner who is also a commuter to systems that are organized collectively with professional drivers, vanpools have long served niche markets. They face the dilemma that passengers must forego any demand for schedule flexibility. There will not be a vanpool following if you miss this one.

JITNEYS. Today Via, a smartphone app-powered service operating in Manhattan advertises “Smarter than the subway. Better than the bus. Cheaper than the taxi.”¹⁴

¹⁴ (Via 2015).

Often illegal dollar vans have long served immigrant communities in New York, Los Angeles, and Miami, serving over 100,000 riders a day in New York.¹⁵ These jitney services run regular routes based on where the market lies, serving a particular set of passengers better than competing modes. The risks with such services are poaching from traditional transit services, which have developed markets in the first place. This issue is discussed in Klein, Moore, and Reja’s

¹⁵ See (King 2012).

1997 book *Curb Rights*,¹⁶ which suggests assigning a property right in stopping to pick-up passengers in a time window at a particular location. These services have also been targeted to better serve the commuting needs of migrant enclaves.

¹⁶ (Klein et al. 1997).

PRIVATE BUSES. Upstart firms like short-lived Leap and Bridj, and Chariot have started to employ smart technology to take advantage of the flexibility of the bus to serve specific passengers rather than general markets.¹⁷

EMPLOYER-BASED TRANSPORT. Companies like Google, Apple, and Facebook operate buses for their employees who wish to live in the City of San Francisco but work in 30-50 miles to the south in Mountain View, Cupertino, and Menlo Park. They differ from traditional macro-transit in that the routes are far more dynamic and personalized for the actual riders, rather than for random, prospective riders. In other words, these are far more demand driven, and despite the size of the vehicle, the networks are typically much smaller (though in the future they may grow). A bus is a bus, but these are institutionally different, as large corporations are assuming the role of transit provider for specialized markets when no one else does.

¹⁷ Upwards of almost 200 public transit startups were identified at the time of writing, <https://angel.co/public-transportation>. Leap has recently been shut down by California for operating illegally.

PARATRANSIT. Paratransit and similar mobility services provide door-to-door shared ride transport for the disabled and elderly in most metropolitan areas. In addition to doing new things, technologies of course enable doing old things better. A thick market in on-demand shared ride micro-transit services may provide a cost-effective, time-saving substitute for current paratransit services.

AIRPORT SHUTTLES. Companies like SuperShuttle have long operated airport shuttles to connect arriving and departing passengers (who did not bring an automobile aboard their flight!) with hotel or home destinations for less money, and less directness but more time than a taxi.

Information technology is enabling large scale shared rides, or micro-transit, just as it enables individual vehicles to provide shared ride service between a handful of passengers. Micro-transit has the potential to address problems in far more markets than it does today.

Most notably, one possible void is that micro-transit services (as well as MaaS Transport) become feeders to public transport's core routes. Addressing the proverbial 'first-mile, last-mile' problem (a space that bicycling also could address) – that gap at the start and end of every trip that's difficult for traditional transit operators to serve in a cost-effective way.

The hub-and-spoke strategy will continue to serve transportation well. How these trunk and feeder systems are organized remains open. Perhaps the public retains the monopoly, capital intensive trunk (macro-transit), but the feeders (micro-transit, MaaS, personal transportation) are private, potentially competitive services. Perhaps the trunks are publicly regulated franchises. Perhaps they are private for-profit firms, as they were originally in many cities.

The degree to which people are willing to share rides to save cost in the future is one of the large unknowns. Will we see a shedding of cars? The twentieth century saw the opposite, a shedding of persons per ride, as first transit, and then carpooling, steadily shrunk. With automation driving costs down, that might continue. But that is offset by information technologies making matching people with others going to almost the same place at almost the same time much more feasible, lowering the penalty associated with ridehailing. How this nets out will determine which technologies will be more successful. There is room for both, but one will undoubtedly be more successful than the other.

What about traditional fixed-route, scheduled bus service? We see it as scaling up to macro-transit bus rapid transit with high frequency on exclusive or prioritized rights-of-way, or scaling down into the more flexible micro-transit market, depending on the route. Real-time, multi-party ride-sharing (MaaS transport) will shave off the very low end of fixed route transit buses that are today provided because a constituency demanded the route decades ago and no one has bothered to remove it. Many of these routes now serve low densities of people who cannot afford a car or cannot drive.

High ridership transit routes will still be best served by high frequency, often rail-based, but also rapid bus, service. But if demand is too low to support high frequency (say 10 minutes), perhaps it is too low to serve with fixed route transit. Admittedly this depends on a variety of factors, like whether fixed route drivers

and MaaS transport drivers have similar compensation. Post-automation, of course, it depends on whether we have driverless buses as well as cars. We will eventually get there, but slowly in the US because of institutional constraints. Fixed route networks will shrink. Low-quality, low-frequency, low-occupancy transit is a flightless bird stumbling toward extinction. However where fixed routes remain, they will increase in frequency and dependability.

Although macro-transit may show some growth in limited markets, alternatives that are already available together with soon-to-be services will outcompete transit for most potential origin-destination pairs. Macro-transit will remain significant in large cities, particularly serving downtown destinations. This has been falling as a share of the total travel market for decades, and while that fall has recently been arrested, the changing nature of work will not restore downtown to its former preeminence.

(DE)CENTRALIZATION. The tension between centralized versus decentralized employment of technology is old. It has played out in factory vs. piece work, trains vs. cars, and mainframes vs. personal computers among other domains. We argue this tension will play out between autonomous privately owned cars and Mobility-as-a-Service. Similarly in transit, this will be an issue. Zealots are convinced there is one true way. This is ultimately a question of costs and benefits, and who bears those costs and benefits.

EQUITY. The problem of transport for those who cannot afford higher quality service will remain, but more efficient means of providing those services than fixed route transit will be sought and eventually enacted, for instance transport vouchers that can be used in a variety of modes.

The transformations of public transit may be more significant than those affecting automobility, occurring for much the same reasons. But while those transformations are larger, in the US, they affect far fewer people, people who live and/or work in medium and high density central cities that can be effectively served with transit, but not those in rural and lower density suburbs without a good street grid.



Figure 12.3: Relax. There's more than one way to get there. Work from Home. Ad on Seattle Metro Transit Vehicle (2001). Photo by David M. Levinson.

13

Up and Out: The Future of Travel Demand and Where We Live



Figure 13.1: New York City is the Up model in extremis, with shared vehicles and transit creating a transport framework that would be unsustainable with mostly private automobiles. Source: Pixabay.com (CCo license).

If there is one thing for certain about the future of transport in cities, it is that autonomous vehicles (AVs) are coming. When AVs will arrive is disputed, and the length of time for their deployment from the first consumer-grade cars to all new cars to replacing the existing fleet is far from clear. Conditional factors include the society's acceptance of technology, regulation, market conditions, and the like.

There are differing projections about the effects of autonomous vehicles on travel demand. Figure 13.2 illustrates these trends relative to a demand line, concomitant with various pressures and effects. We present, on one hand, how automation, in and of itself, is a technology that makes travel easier; it pushes the demand curve

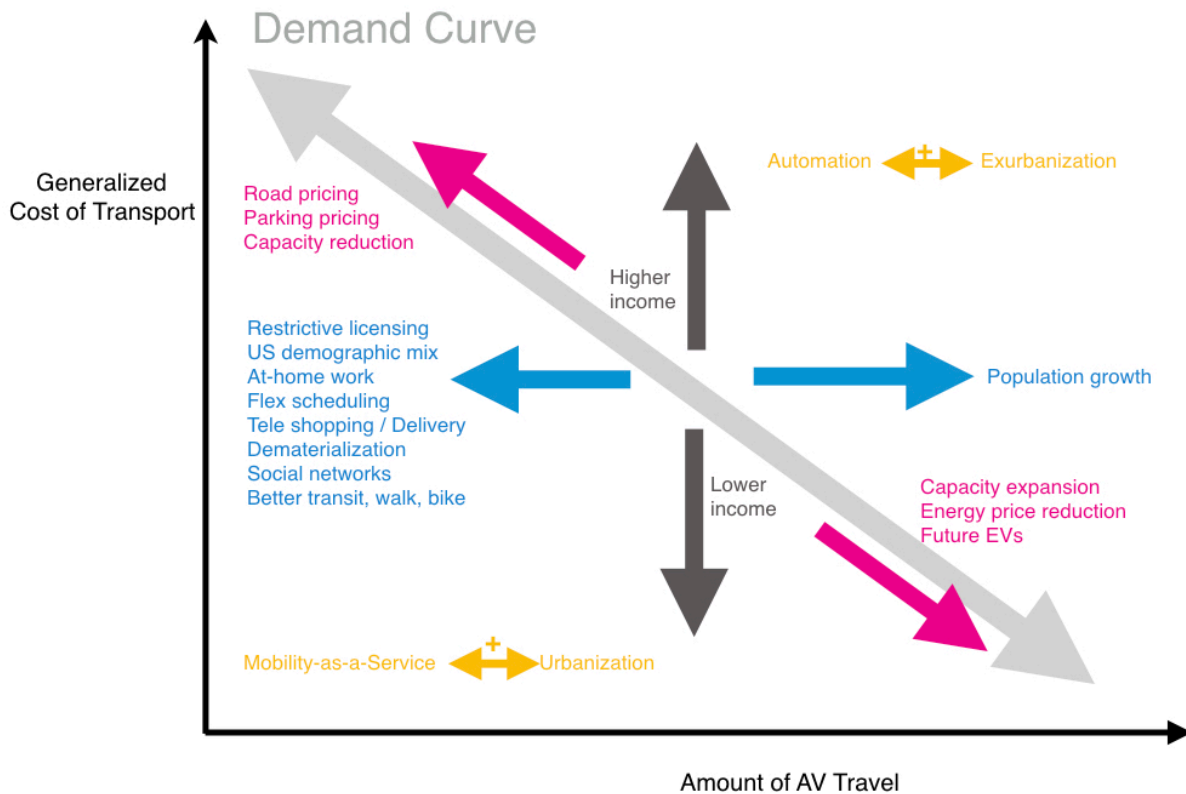


Figure 13.2: The effects of accessibility on cities.

to the right. For the same general cost, people are more willing to travel. Exurbanization has a similar effect (and automation and exurbanization form a positive feedback system).

We also present, on another hand, how the move from private vehicle ownership to mobility as a service, which is likely in larger cities, suggest that the marginal cost of a trip might rise from very low (since the vehicle is already owned) to high (since the cost of the vehicle has to be recovered on a per-trip basis). This moves the demand curve to the left. The effect is similar in effect to urbanization (and urbanization and mobility-as-a-service also form a nice positive feedback system). Many other changes also move the demand curve to the left, including demographic trends, substituting information technologies for work, socializing, and shopping, and dematerialization.

Income moves the willingness to pay for the same amount of travel up or down. Changes in the price structure of travel move along the demand curve.

The culmination of these factors suggests one scheme to consider the effects of new technologies on travel demand. How these vectors net out is a problem that could be solved with analytical geometry, if only the relative magnitudes were known. We suggest herein that demand in the US is generally moving a bit more to the left than the right. Yet, transport conditions in the US within the past year witnessed relatively low fuel costs and growing incomes; thus, aggregate behavior signaled movement to right than the left. We also note, however, that new automation technologies change the available capacity of roads through improved packing of vehicles in motion and smaller vehicles. Less demand layered on more effective supply reduces congestion effects in the net.

Relative to traditional cars driven by humans, AVs will generally allow individuals faster travel. There will always be exceptions, yet, all else equal, faster vehicles increase demand. Each technological advance in mobility over the past 100 years heretofore increased the size of metropolitan areas. The ability to go faster, either owing to new technologies or more connected networks, allows people to reach more things in less time. Subways drove the expansion of London.¹ Streetcars did the same for many American cities.² Historically, the time saved from mobility gains was reflected mostly in additional distance between home and the workplace, maintaining a stable commuting (home to work) time.³

Will autonomous vehicles reverse the trends that have been witnessed with current car technology? Will people make more trips? Will people make longer trips? Will people relocate? All are good questions. There are increasing anecdotes – soon to be solidified with loads of empirical data – to shed light on these important questions. Nonetheless, any findings will likely be highly contextualized and therefore, perennially difficult to claim for aggregate populations.

Recent evidence on reduced travel distances and time spent traveling is less about reducing trip distances between home and work (which if anything are still rising in the US) and more about reducing the sheer number of work and other trips being made across the whole population. In short: speed decentralizes.⁴ And, some places, including suburbs, exurbs, and rural areas will likely see increased decentralization. But in cities, we observe faster growth rates than the suburbs and then seen in cities in recent decades. These phenomena will likely be context dependent.

¹ (Levinson 2007).

² (Xie and Levinson 2009).

³ Autonomous vehicles clearly alter the impedance function of accessibility calculations – in which direction remains an open question. One reliable estimate suggests a one percent increase in accessibility leads to a 0.6 percent increase in travel. Couple this increase with the new mode of cars deadheading without people, and perhaps the doubling of capacities and speeds leads to a doubling of total travel, assuming nothing else changes.

⁴ In addition to speed, anything that lowers the generalized cost of travel decentralizes development.

Autonomous vehicles will likely be faster, particularly on freeways, especially after widespread deployment once either human drivers are banned or a network of separate lanes are designated for autonomous cars.

Coupling with just the faster speed, the fully autonomous vehicle lowers the cognitive burden on the former driver/now passenger. Modes with lower cognitive burden tend to have longer trip durations. Time matters. What you do with that time (the quality of the experience) also matters. If you can work while traveling, the value of saving time is less than if you must focus on the driving task. This phenomenon helps explain a premium commuters are willing to pay for high-quality transit and intercity rail service. Pursuit of high-specification ride-quality raises interesting issues about acceleration and motion sickness (which is worse for passengers than drivers as passengers cannot anticipate as well as drivers).⁵

⁵ (Le Vine et al. 2015).

If the time or money cost of traveling per trip declines, the long-held *theory of induced demand* predicts, all else equal: more trips, longer trips, and more trips in the peak period. Logically, if the time or money cost per trip rises, there should be fewer and shorter trips, or *reduced demand*.

Privately owned autonomous vehicles lower the cost of travel per trip. Mobility-as-a-Service (MaaS) eliminates the fixed cost of transport, and exchanges it for a higher per cost trip. The share of ownership versus MaaS is thus an, if not the most, important predictor of travel demand in the coming years.

But two seemingly contradictory, but complementary, outcomes are likely as vehicular automation and Mobility-as-a-Service play out.

As the chapter title suggests, we label these scenarios 'Up' and 'Out.'

UP: LESS VEHICLE OWNERSHIP WITH INCREASED USE OF MAAS IN CITIES, RAISING THE VALUE OF CITIES.

Cloud Commuting via Shared Autonomous Electric Vehicles (SAEVs) which can be summoned on demand allows people to avoid vehicle ownership altogether. This reduces vehicle travel, as people pay more to rent by the minute than exploit the sunk costs of vehicular ownership. By saving total expenditures on transport, more funds are available to pay for rent in cities, and more trips are by walk, bike, and transit. People who seek the set of urban amenities (entertainment, restaurants, a larger dating pool) will find these amenities increasing in response to the population. The greater value in cities with the new more convenient technology leads to more and taller development. (Hence the use of the word *Up*.)

OUT: MORE VEHICLE TRAVEL WITH INCREASED EXURBANIZATION.

Fast Private Autonomous Electric Vehicles (PAEVs) that allow their passenger to do other things than steer and brake and find parking impose fewer requirements on the traveler than actively driving the same distance. Decreases in the cost of traveling (i.e., availability of multitasking) makes travel easier. Easier travel means increases in accessibility and subsequently increases in the spread of development and a greater separation between home and work, (pejoratively, sprawl), just as commuter trains today enable exurban living or living in a different city. This reinforces the disconnected, dendritic suburban street grid and makes transit service that much more difficult (as if low density suburbs weren't hard enough). People will live farther *Out*.

13.1 *America's Greatest Natural Resource*

"Parking is America's greatest natural resource." – David King.

A direct knock-on effect of the Up scenario is that it will transform the need for parking. It also means vehicular dead-heading.⁶

At the more local, urban level, the Mobility-as-a-Service model implies spaces now devoted to cars can be repurposed – everything from street space to buildings. Garages turn to accessory dwelling units. Gas stations and parking lots to anything with a "higher and better use." Autonomous vehicles can drop off their passenger at the front door, and then park themselves in far less space than drivers currently require (or move on to their next passenger), and that space need not be so close to the most valuable urban areas.

⁶ Dead-heading is not a continued tribute to the psychedelic band formed in 1965, but rather cars driving without any occupants to their next call, a phenomenon common with transit and rail, though even those vehicles usually have drivers.

Furthermore, MaaS signals an end to on-street parking, suggesting yet another implication for the future of how roads will be reconfigured. “Redeveloping surface parking may be the single biggest challenge facing US cities, but is also a rare opportunity for cities and many suburbs to rebuild themselves fairly easily and quickly.”⁷

⁷ Email correspondence with transportation planning professor David King.

13.2 *Humanity, the Future, & Its Implications for Cities: A Quick History*

We present a short history of humanity:

In the beginning, people lived in caves. Once they ran short of caves, humans built huts. Before agriculture, the only land uses were caves, huts, and vastly more space for hunting and gathering.

Eventually, enough was gathered (and agriculture was developed) that warehouses of a sort were constructed to store foodstuffs for future use.

Enough was traded, that a blanket on the ground became a table became a tent became shops (retail land uses). Places of worship moved out of the living room into a common structure, or communal fire pits were enclosed. Manufactured goods moved from the home to a workshop to a factory. Bureaucracy itself required its own spaces.

The modern world was created.

⁸ (Oldenburg 1989).

In the book, *The Great Good Place*,⁸ Ray Oldenburg references a Third Space – neutral spaces on neutral ground where people gather and interact. Third spaces differ from First space (home) and Second space (work or school). Oldenburg and other sociologists bemoan the fact that Third Spaces are in rapid decline.

One reason for this emerging phenomenon is that First space has increased in size. There is less reason (and it is costlier) to go to a pub or a coffee shop when one owns their wet bar in the basement, complete with video game entertainment system. With many homes currently spread out in a low density environment, the preference for remaining put is easier to understand. Importantly, today’s large homes with their ability to leverage information (and entertainment) technologies are much more attractive than homes just five years ago. People don’t want to leave. The notion of free-range children is the exception, and this is not just because parents are overly protective [David’s neighbor returning his son Sam back home because Sam was pretending to stand guard outside her house across the street], but because children aren’t as bored in the home with their devices as they are outside the home without them. And when the neighbor kids stay at home, the outdoors is even less entertaining as there is no one else to play

with. It is a vicious cycle with the natural end state that no one plays outside. With the internet and its billions of cat videos, plethora of video games, and any music one could want, along with instant virtual connectivity to anyone anybody might want to socialize with, there is mounting evidence to suggest that people are refraining from the need to go out.

In recent years, urbanized areas in the US have seen obsolete land uses revert back to housing. Similarly, there has been a conversion of old industrial lofts to housing, transformation of offices to housing. Cities are adding far more housing space as a share of new development than in previous decades. Retail spaces are being abandoned and repurposed.

Automation means that:

- Manufacturing and warehousing have even fewer ties to the labor force than before, and so are even more footloose (to locations where the cost of robots and transport of materials to the site and transport to end users is lowest),
- Transport costs drop, and depend primarily on the value of time of the goods being moved, wear and tear on vehicles, and the costs of energy (which are falling),
- Agriculture and food production are more like manufacturing than artisan craft-work. While manufacturing and food production will require space, they do not necessarily require space inhabited by people.

To the extent that people will be employed, they will less and less need to work any particular place. They may need to meet with others, but that need not be at one another's cubicle. Second space will disappear. This may result in an increase in Third space as humans, at least the extroverts among you, and even introverts in extrovert mode, still want some face-to-face interaction. But what is to say that won't occur in people's large, large homes? In a world with authenticated people identifiable from facial recognition by your smart home and with established identities and reputations, the threat of inviting a 'stranger' into your home, or the public portion of your home may no longer be so frightening, as no one is really a stranger anymore. The greater threat will be meeting someone in a public place where you don't control the environment.

In the end, like in the beginning, the only built structures people require is housing. Second space will slowly diminish. An open question lies in whether a Third space can fill the gap. While transport automation is changing cities as discussed above,

automation more broadly has the potential to more profoundly change the function and nature of cities.

13.3 *Replacing and Adapting Retail*

Although physical transactions are here to stay, if only for the raw materials needed to operate 3-D printers (Chapter 10), going shopping in the physical world has peaked (Chapter 3).

Fortunately, a lot of the retail that will disappear is, for lack of a better word, crap. We all know the dumpy strip malls that besot the scorned suburban landscape. First they will lower rents, attracting bingo halls, massage parlors, karate schools, and board game shops. Second they will be abandoned. Then they will be replaced.

As with many of these processes, there will be a rich get richer phenomenon, a few remaining retail centers may continue to grow, as the experience of shopping (requiring many many choices) replaces the necessity of shopping. The commodity distributors will be replaced by commodity deliverers if the cost of distribution can be flipped so that delivery is cheap enough. But people still need to leave home, if only to get out of the house. Looking at things is a good excuse. Artisans and crafts, and things that are more attractive in person than online will be the things that motivate us to leave the home-work axis for alternative destinations. The purchase of stocks like paper towels or detergent will rarely be stimulating enough to get us out of our chairs.

As shopping transitions from the real to virtual, some, if not all, of the land that was devoted to shopping (14.2 billion square feet (1.32 billion m^2) will need to be reallocated.⁹ The UK has the world's largest e-commerce share of retail, accounting for 13% of their total retail sales¹⁰ and their Parliament has noticed this trend, introducing legislation specifically designed to preserve High Streets and help small businesses.¹¹ But with what will we replace the losers? As opportunities for re-development arise, better regulations and incentives will lead incrementally to more desirable land use.

Advocacy groups like Smart Growth America predict a robust future demand for hundreds of millions of square feet of walkable urbanism over the next generation. They go so far as to claim that once the real estate industry "better figures out" how to build this style of development, it will mark the end of sprawl. Such optimism claims a new foundation for the American economy (in the same vein that the suburbs and driving underwrote much of the American economy for many years). We are less convinced this the

⁹ For perspective, the Mall of America is 4.2 million square feet, of which 2.5 million is retail. So US retail is basically 3000 Malls of America.

¹⁰ (eMarketer 2015).

¹¹ (All-Party Parliamentary Small Shops Group (APPSSG) 2006). 'High Street' is the British equivalent of 'Main Street,' though it applies to neighborhoods within cities as well as small towns.

new real estate model will comprise a walkable Main Street, if only because the demand for shops will decline. The demand for services like eating out may continue to grow though, as shown in Figure 11.2. People will not want to just stay at home. Recreation and entertainment are among other possibilities.

These older less desirable retail areas are the tear-downs. If they retain good transport access, they might remain commercial, or be appropriate for medium or high density residential (Building 'Up').¹² While the highest and best use may not be retail stores, there are still other activities that benefit from locations that are easily reached.

As fetching is replaced by delivery (especially by automated delivery), the amount of shopping (and naturally, the space devoted to shopping) will shrink. This is counter-balanced by trends toward greater income¹³ (which ultimately must be spent on something) and more available time (which also has to be spent on something), for which shopping may be an attractive solution.

Sometimes, the architecture, history, culture, food of the place itself will attract people. Outside of the US and China, the top world tourism destinations were France (mostly Paris), Spain (mostly Barcelona), and Italy (mostly all over) (the US and China are arguably at the top of the list as large countries with internal in addition to international tourism). Creating and developing attractive places, ranging from historical and attractive Main Streets to the recreated militarily significant outpost is one of many ways to give people something to do with their time while separating them from their money.

¹² (Dunham-Jones and Williamson 2008).

¹³ There is no guarantee that GDP, GDP/person, or personal income will rise. In the US GDP, which is a function of the number of people and productivity per person, has risen, but has not translated directly into rising individual incomes. In the UK average personal incomes have fallen. See (John Polak and Scott Le Vine 2014).

13.4 Discussion

At first blush, *Up* and *Out* appear to be contrasting scenarios; they are not exclusive, however. More people living in the suburbs or exurbs does not mean fewer people live in cities, because the overall size of the pie increases (more people overall). We predict pushing on both ends of the demand curve places more growth in central and exurban locations, and less in existing low-density suburbs.

Similarly, as the cost of travel decreases, people will be more willing to live in locations far from where they work. For example, some of our Dutch transport colleagues live on opposite sides of the country from where they work (a phenomenon relatively common in the Netherlands), relying on the convenient bike-train network. The Northeast Corridor of the US has people living in one city and commuting to another (for instance from Washington to Baltimore, Philadelphia to New York). At speeds of 100 miles per hour (160

km/h), the commuting range expands widely.

It is entirely likely that forms of transport propelled partially by humans and electricity (sourced by solar power), will greenwash a new generation of dispersed development. The effect may result in future exurbs imposing a smaller environmental footprint than today's cities, if not a smaller footprint than future cities.

Relaxing demands on time, owing to the decline in the commute to work, routine shopping, the parent-taxi, and so on, invokes the perennial issue of travel time budgets. People will need to find new uses for that time. So time not spent at work or out shopping or traveling must be spent on something. Certainly some of that could just be time at home. And as people live in more preferred places, they may want to stay at home for longer times (and thus want to make their homes larger, facilitated by building 'Out'. But some of it will also be spent outside the home, which is easier in the denser environment of 'Up'. People go 'stir crazy' and have an innate need to roam – and will find excuses to do so.¹⁴

¹⁴ See (Marchetti 1994). Also see the work of Yacov Zahavi on travel time budgets, archived at <http://www.surveyarchive.org/zahavi.html>.

Work and shopping always had a social element that will continue in some other form, these forms will be as diverse as people are. That roaming need not be at 7:30 am and 4:30 pm, but it is still likely to be some amount of time at some time of the day. It need not be to the office or supermarket or bank or day care. It need not involve gripping the steering wheel of a two-ton vehicle powered by petrochemicals in a violent *Death Race*,¹⁵ but will involve motion, motorized or otherwise.

¹⁵ See e.g. *Death Race 2000*, a 1975 Roger Corman film.

The interplay of AVs and pricing is especially important. While autonomous vehicle capacity may eventually double or quadruple, per capita demand will rise as well if traditional patterns of induced demand hold, and people continue to work, shop, and play at today's rates. It is quite possible that sharing remains a niche while most people choose to own their own cars – the *Out* scenario dominates. Thus, exurbanization and AVs better leverage newly available capacity. To fully mitigate expected congestion effects, pricing is required (see Chapter 15).

Part III

Policy

Reduce, Reuse, (re)Cycle

Figure 14.1: Narrowly marked street lane in Palermo, Italy. Photo by Kevin J. Krizek.

"I said the numbers before. 114,000 lane miles, 25,000 bridges, 4,000 miles of rail. I said this a lot in my conversation when we were talking about fuel tax increases. It's not affordable. Nobody's going to pay.

We are. We're the ones. Look in the mirror. We're not going to pay to rebuild that entire system.

And my personal belief is that the entire system is unneeded. And so the reality is, the system is going to shrink.

There's nothing I have to do. Bridges close themselves. Roads deteriorate and go away. That's what happens.

And reality is, for us, let's not let the system degrade and then we're stuck with sorta whatever's left. Let's try to make a conscious choice – it's not going to be perfect, I would agree it's going to be complex and messy – but let's figure out which ones we really want to keep.

And quite honestly, it's not everything that we have, which means some changes.

– Paul Trombino, the director of the Iowa Department of Transportation.¹

¹ (Marohn 2015).

To minimize physical waste, the slogan “Reduce, Reuse, Recycle” is ingrained into grade school children in the US; the mantra emphasizes the need to:

1. Reduce waste,
2. Reuse what is available, and then
3. Recycle what remains.

A starting point for how to approach transport facilities – mainly the space between buildings in the form of roads – modifies this mantra to Reduce, Reuse, (re)cycle.

Figure 14.2: Crime alert: theft of bicycle reported in this vicinity - Singapore. Shared bikes with embedded GPS may obviate this problem. Photo by David M. Levinson



14.1 Reduce



Figure 14.3: Bike or motorcycle?

Reducing overall travel demand helps and congestion pricing is undoubtedly the most effective strategy in the near term; we tackle pricing and cost issues in Chapter 15. We first motivate and prescribe tactics for more efficiently employing the existing transport supply.

A popular gripe is that congestion stems from scarce right-of-way (scarce in that it is limited, and finite, and at times fully used given the applied technologies for its use). What goes unrealized is that collectively, this scarce and valuable resource is sorely wasted:

- Most roads are under-used most of the time. There is ample capacity outside the peak.
- Most of the pavement is unused even at peak times; there are large gaps between vehicles both in terms of the headway between vehicles and the lateral spacing between vehicles.
- Most Americans drive 6 foot wide cars in 12 foot lanes, often on highways with wide shoulders.
- Most seats in most cars are unoccupied most of the time.
- Most cars contain far more weight than required to safely move the passenger. While bigger cars *might* be safer for the occupants, they are less safe for non-occupants.² This is an inefficient arms race.

If we follow the “2 second rule” (2 seconds between two successive vehicle’s front bumpers) (or 1800 vehicles per hour), at 60 mph we have a vehicle density of 30 vehicles per mile, or 176 ft per vehicle. Obviously with congestion, we are wasting time because we don’t increase throughput and we decrease speed, though we increase density. Vehicles are typically 26 ft, so we are using about 7 vehicle lengths for every vehicle we are moving at free flow speed near maximum stable throughput on a pipeline section without a bottleneck.

²On the discussion of whether lighter cars are more unsafe: (Wang and Kockelman 2005).

- Many roads are so wide we use them for storage of vehicles most of the day.
- There is excessive delay at traffic lights, especially during off-peak periods, wasting time and space.

Prior to costly road expansion, either in terms of wider facilities or more rights-of-way, the transport sector is wise to realize the urgency in adopting strategies to more efficiently use the scarce, but *existing*, right-of-way.

VEHICLE WIDTH/LANE WIDTH. Even without autonomous vehicles, lanes narrower than US standards are safe and have similar throughput.³ Driving in narrower lanes prompts increased anxiety and awareness and hence safer driving conditions. Few, if any, communities in the US are willing to dip below 10 foot, marked travel lanes, even for neighborhood streets. Even the most progressive public works officials are unwilling to go south of that. Meanwhile, European communities are repeatedly penning in 6 foot (~2 meter) lanes, as illustrated in Figure 14.1.

Looking forward, driverless cars will likely have far less variability in the use of the lane. Other vehicles are just skinnier: bikes, mopeds, motorcycles, e-bikes, neighborhood electric vehicles, and so on. With these vehicles, personal mobility uses less space.

VEHICLE WEIGHT. The safety benefits of lighter cars, trucks, and buses are relatively straightforward from the standpoint of physics. The average car in the US weighs in excess of 2 tons; European averages are roughly two-thirds of that. Most cars are carrying around far more weight than required to safely move the passenger. While bigger cars tend to be safer for the occupants, they are less safe for non-occupants. The greatest risk is when a heavy truck meets a small car at high speed, or worse, an unprotected pedestrian.

There is enormous potential to realize heightened use of neighborhood type vehicles for neighborhood travel (i.e., more specialized, local, lower speed travel). Ratcheting down the vehicle size arms race is challenging; it is unclear where Detroit's Big Three automakers⁴ stand on smaller cars given the large profits in big cars – they make them because they have to satisfy fuel economy standards. However, the economics of electric vehicles help in this regard.

VEHICLE OCCUPANCY. Cities should legalize real-time, *ad hoc* ridehailing (with compensation for the ride provider) to better use

³ (Potts et al. 2007).

⁴ The Big 3 in Detroit refers to the three major American automotive companies: General Motors, Ford, and Chrysler. (Chrysler is now owned by Fiat.)

excess capacity within vehicles. In many places the compensation is illegal, a battle discussed in Chapter 8 on MaaS Transport, as it looks and smells like a taxi, which are highly regulated. For example, strategies to encourage drivers to share (for money) excess seats in cars are sorely needed.

TRAFFIC SIGNALS AND STOP SIGNS. More cars need to be moving more often, thereby reducing idling in the system (i.e., the amount of time people spend ‘in-vehicle’ that are not actually in-motion). Strategic use of roundabouts (both mini-roundabouts in residential areas as well as full-size roundabouts at suburban arterials) helps reduces delay compared with stop signs or traffic lights, and increases safety. The Dutch are among the innovators in this respect.

For example, Bertus Fortuijn, a Dutch traffic engineer, designed the turbo-roundabout as a high-capacity, safe, no-signal traffic control system.⁵ A remarkable design solution, it prompts travelers to choose the correct lane on approach, thereby avoiding lane changes within the roundabout. The design limits the number of possible conflicts, so that drivers only have to look one direction, in a routinized way, without the need to use mirrors, etc. Traffic moves slowly (but faster than at a stoplight), yet overall capacity remains high.

⁵ A video of the Turbo Roundabout is shown at this link: <https://www.youtube.com/watch?v=iMYib3IR43I>.

As autonomous cars aim to increasingly navigate through normal junctions, designs like these could be a huge ally.

The urban arterial street grid will likely remain signalized, but more real-time intelligence in the controllers, vehicle sensors, and eventually vehicle to infrastructure connectivity (Chapter 7) can significantly reduce stopped delay.

If vehicles and inter-vehicle communications were better, it would be possible to achieve real-time coordination of vehicle movements. A new goal will be to eliminate almost all stopped delay at uncongested intersections that are today signalized. Pedestrian/vehicle conflicts still remain and require controls or grade separation when speeds are high and spaces are demarcated rather than shared. The consequence of implementing the above changes is that space devoted to cars can be reduced, both without, and especially with, new vehicle technologies. The logical next step is to reallocate road space.

14.2 Reuse: Rightsizing Roads

Figure 14.4: Installation of the street repurposing project in Boulder. Photo by Kevin J. Krizek.



⁶ This is not to say there are no good projects, just very few. Redundancy for critical facilities matters, and as old bridges and tunnels are removed, something needs to take their place, ideally before they are decommissioned.

To the dismay of many transport planners and engineers (many of whom got into the field to build things), the physical layer of the urban surface transport network in the United States is largely complete.⁶ Remaining projects are largely those too expensive to build the first (or second, or third) time (much like the Second Avenue Subway in New York or the Alaskan Way Viaduct in Seattle). Such 'Zombie' projects do not die. While construction is essentially irreversible, non-construction is easily reversed. In the end, such projects are tinkering at the edges. Given the small amount of new construction, most travel 20, 30, or even 50 years from now will be on roads that exist today. While populations are growing in central cities in the US, most older cities have infrastructure networks designed for an era when populations were larger than today.

Demassification (Chapter 9), changing the dimensions of cars is a first step to glean increased efficiency within existing rights-of-way. But broader thinking reconceptualizes the inherent design of rights-of-way – that is, the area of space that is typically reserved for public use between buildings.

We mentioned earlier, roads are among the slowest forms of technology. While *roads aren't going anywhere, how society uses them is*. The space in the right-of-way will continue to serve as the primary

conduit for moving matter: people and goods, even if the amount of matter that needs to be moved declines. But as modes of travel are born and die off, the nature and composition of these conduits (roads) are likely to undergo dramatic and frequent changes.

The share of space that will be devoted to any one mode – or portions devoted to mixing modes – will need to be addressed. A first realization stems from what we mentioned above: narrower lanes for car users has advantages. European-traveled readers observe how cars – and lane widths and overall transport facilities operate safely at widths that are half of what they are in the US. For instance, two six-foot lanes could serve narrow vehicles in place of one traditional twelve-foot lane. Modern US lane widths are ensconced in standards,⁷ and changing them requires changing standards. Like lane widths, road widths are set by standards, often driven by fire departments who are adverse to putting their trucks in reverse.

⁷For more on roadway standards, see: http://nacto.org/docs/usdg/residential_street_standards_benjoseph.pdf.

But more broadly, critical questions for communities of all sizes will revolve around how much of what space goes to what forms of movement, to vehicle storage, and to other uses. This means changing the proportions and purpose for how this space is used.⁸

⁸(Rice 2015).

Rightsizing or repurposing roads can take many forms. It has usually been done at a fraction of the cost of building new transport infrastructure from scratch and might result in moving more people. It can mean taking away a shoulder and installing a bus rapid transit lane. It can mean a 4 lane to 3 lane (4-3) conversion (2 lanes to 1 in each direction, with a center turn lane). It can mean replacing a vacant 12 foot median with a light rail route. But these are examples with excess space that might be empty in the right-of-way. What happens when all space in the right-of-way is spoken for? What happens when people say all of that is needed for cars? In these cases, space for other uses comes at the expense of automobile capacity – currently a difficult sell in all communities. However, such cases are becoming more frequent, therefore creating greater precedent, and ultimately making such cases more palatable to accept politically.

14.3 *Five Stages of Repurposing*

Communities across the globe are at different points on the spectrum for accepting rightsizing or repurposing arguments. We (undoubtedly mis-)apply the Kübler-Ross model of grief felt by the motorist at the forthcoming loss of automobile roadscape for cycling facilities.

STAGE 1: DENIAL applies to most communities across the US, whose residents refuse to acknowledge that street space will be or needs to be changing. In fact, there might be efforts to find additional space for auto capacity (e.g., more roads, more lanes, wider lanes, more parking). To the degree that bike lanes are considered, they are found on otherwise empty space within existing rights of way (e.g., excessively wide shoulders). *Examples: Anytown, USA.*

STAGE 2: ANGER is exemplified by the so-called “War on Bikes” and “War on Cars”⁹ that are riveting cities trying to make modest changes, like replacing parking with bike lanes or designating ‘bicycle boulevards’. *Examples: New York, Washington DC, Toronto.* Even relatively progressive towns like Boulder, Colorado – which has spent little, if any, political capital in efforts to repurpose auto space in recent years – have recently disturbed the hornet’s nest; much of the driving public is angry owing to recent street repurposing experiments like the one in Figure 14.4.

STAGE 3: BARGAINING refers to desire to re-design select areas to reduce auto presence. It might be traffic calming. Maybe it is a commitment to not build more roads, expand lanes, or increase the level of service of intersections. Given that potholes are sometimes conceived of as an original form of traffic calming, select stretches of roads might be left to wither, while other stretches might be better maintained to support increased variety of use. But the reach of these areas is increasing. *Examples: St. Paul, Minnesota.*

STAGE 4: DEPRESSION builds on Bargaining as the perceived losers in the War on Cars (drivers) stop fighting the extension of non-auto infrastructure into full corridors. Efforts might be centered on longer stretches of road where there is a willingness to reduce lane capacity. Since the first section of bike lanes already created a bottleneck for cars or eliminated parking, extensions matter a lot less. *Examples: Minneapolis, Minnesota.*

STAGE 5: ACCEPTANCE means community-wide consensus to

⁹ The discussions about “War on Bikes” and “War on Cars” are overwrought, but have captured media attention, see e.g. (Byron 2015; Alpert 2013). Toronto’s highly entertaining Mayor Rob Ford talked about the “War on Cars” (Markson 2010).

reduce auto space by removing on-street parking overall, installing parking in former vehicular lanes, or any of a series of other treatments (e.g., buffered bicycle lanes, bulb-outs). Few places have achieved this level of nirvana but some Northern European places are closest. *Examples: Davis, California and parts of Portland, Oregon.*

A similar argument would apply to bus lanes or pedestrian spaces; we leave those as an exercise for the reader.

Residents sort themselves in urban environments, selecting the environment that best enables them to lead the lifestyle they seek. People who want to cycle will move to places where cycling is easier. People who want to park will do likewise.

In one sense, the amount of space in a right-of-way is a zero-sum game. In another, because that space is not fully utilized, better allocation of that space makes this a positive-sum game, the gain for 'the winners' outweighs the loss for 'the losers'. The challenge, which is why local city officials and city planners are handsomely rewarded in their occupations,¹⁰ is to share that gain somehow so as to convince 'the losers' to not fight what is best for society as a whole.

14.4 Reuse Tactics

More concretely, an outstanding challenge moving forward is how to reconcile the need for hard infrastructure with the uncertainty about what technology (and the future) provides.

One approach is seeded via the Mike Nichols film *The Graduate*. Dustin Hoffman's character (Benjamin Braddock) is advised by Walter Brooke (Mr. McGuire) about the future:

Mr. McGuire: I want to say one word to you. Just one word.

Benjamin: Yes, sir.

Mr. McGuire: Are you listening?

Benjamin: Yes, I am.

Mr. McGuire: Plastics.

Benjamin: Exactly how do you mean?

Mr. McGuire: There's a great future in plastics. Think about it. Will you think about it?

"ONE WORD – PLASTICS." THIS ADVICE WAS NOT TOO BAD FOR 1968.

PLASTICITY. The quip can be rephrased for a transport context: "One word – Plasticity" where plasticity is defined as the ability to change in response to changes in the environment. This may be

¹⁰ City officials and planners in the US are of course not especially handsomely rewarded while working for government. David's first job was at MNCPPC-MCPD (Montgomery County, Maryland Planning Department) a land regulation agency. His colleague Ajay told a friend in India that he worked for the agency. His friend said "you must be rich", due to the huge opportunities for bribes. As far as David knows, no staffers were bribed at the agency.

good or bad (e.g., plastic deformation in structures would largely be considered bad). But given that matters are changing quickly and the accuracy of forecasts are even more suspect than they used to be (and in prior decades, their worthiness was questioned considerably), communities need transport and land use designs that are adaptable. Future transport infrastructure needs to easily change function over time. Adaptability (the ability to change) and flexibility (the ability to do more than one thing, like serving cars, trucks, buses, and bicycles) are paramount.

The prevailing tenor of most transport planning focuses on the built environment, embedded infrastructure, and long-lasting constructs. Such hallmarks are indicative of anti-plasticity. But this is changing. An expert panel of transport specialists from the US recently came to the following conclusion:

“The current ‘predict and provide’ paradigm in transport – in which transport officials plan infrastructure investments based on projected needs 20 or 30 years into the future – was seen as imperiled amid stalled driving demand and growing interest in multimodal alternatives.”¹¹

¹¹ (Dutzik et al. 2015).

The tone and content of transport conversations have evolved over recent years. There has been noticeable change away from the primacy of congestion and level of service measures toward a stronger need to prize access and opportunities. Charging users for both roadway use and parking have gone from almost untouchable to widely accepted in the policy sphere. A next threshold will prize doing more with less. It will require creativity about what types of infrastructure are best served and placed within limited right-of-ways currently available. Infrastructure decisions based on a guiding principle of ‘plasticity’ is easier to laugh off than take seriously. New plastic, adaptable, and flexible designs for transport – land use systems are the keys to progress.

PLASTICS. One place to start implementing the notion of plasticity uses actual plastic. This requires re-adjusting notions of what comprises infrastructure. Communities test waters of road repurposing for bicycling, for example, by turning to plant-filled, orange five-gallon buckets from your local hardware superstore, or strips of green astroturf.¹²

¹² (Anderson 2014).

These type of initiatives are termed ‘tactical urbanism’ or ‘guerrilla traffic calming.’¹³ Sanctioned or unsanctioned by the community, the result might be parklets, ‘Pavement to Plaza’, or ‘Build a Better Block’ initiatives. These are small-scale interventions with a community-focus and a local scale. Their main purpose is to test the notion of

¹³ Some say a more “strategic” variant is referred to as tactical urbanism. See (Lydon and Garcia 2015).

how a place works or is perceived.

These types of initiatives allow shorter time horizons. They may be dismantled at the end of the day. Assuming stronger materials, they may have a shelf life of mere months. Communities like Boulder, Colorado are launching formal programs to roll out smaller scale, relatively radical bicycling infrastructure to test the idea.¹⁴

¹⁴ (City of Boulder).

A key characteristic is that nothing is permanent. Furthermore, the performance of the intervention is a key design ingredient. It may flail or fly.

PAINT. Heat plastic to the point that it becomes paint and there is a powerful lever in transport circles. Peter Rogoff, the former US Federal Transit Administrator is on record as candidly stating some of them: painting buses and painting roads,¹⁵

¹⁵ (Hyman 2010).

“Supporters of public transit must be willing to share some simple truths that folks don’t want to hear. One is this – Paint is cheap, rail systems are extremely expensive.

Yes, transit riders often want to go by rail. But it turns out you can entice even diehard rail riders onto a bus, if you call it a “special” bus and just paint it a different color than the rest of the fleet.

Once you’ve got special buses, it turns out that busways are cheap. Take that paint can and paint a designated bus lane on the street system. Throw in signal preemption, and you can move a lot of people at very little cost compared to rail.” – Peter Rogoff, the former US Federal Transit Administrator

When it comes to painting roads, countries, states, regions, and even cities have their own guidelines for using paint. Janette Sadik-Khan who was Commissioner of New York City’s Department of Transportation during the Bloomberg Administration was all about paint, using it to rapidly test alternative street configurations.¹⁶ Such efforts in New York helped, in part, to stimulate one such national guide in the US from the influential American Association of State Highway and Transportation Officials (AASHTO).¹⁷ It covers standards such as bike lane width. Then there is the *Manual on Uniform Traffic Control Devices* (MUTCD) from the Federal Highway Administration¹⁸ covering signs, signals, and pavement markings, each state has its own version. The MUTCD does authorize experiments. They grant interim approvals for some uses. But the MUTCD is slow to make them official and they are usually conservative in scope. Work from the National Association of City Transportation Officials (NACTO), now led by Janette Sadik-Khan is pushing the envelope with respect to innovation, complete with a step towards standardization. While

¹⁶ (Whitaker 2007).

¹⁷ (AASHTO 2012).

¹⁸ (Hawkins 1992a;b;c; 1994).

National Association of City Transportation Officials (NACTO), the Federal Highway Administration, and hosts of other bodies stipulate how paint should be used in the form of design recommendations, we propose three areas of use:

- *Conflict zones*: paint should be used to highlight difficult conflict through junctions. For example, almost 80% of bicycle crashes occur at intersections (and merge zones).
- *Something special*: paint should be used to indicate an exceptional treatment. For instance for bicycle facilities, these could include the start (or end) of a protected lane, a left turn waiting area or a bike box, for instance.
- *Aggressive experiments*: in the forthcoming evolution of how street space will change in cities, paint is the friend of the transport planner. Paint could be applied more liberally when cities are trying something avant-garde, realizing that it might be more difficult to do on streets (like those in Europe) that are comprised of different types of bricks or cobbles. Paint can be used more aggressively to signal notable experiments where roads are being repurposed. The new or experimental nature demands more attention. Once it is no longer new (after a year or if it is deemed not to work) then it could be erased or put out to pasture. Ideally the design itself is self-explaining, but drivers are thick and engineers are nervous.

The question of how to occupy the space that will be reaped from both road repurposing and possible paint delineation is a big one. Cars can do just as much (if not more) with less space (owing to automation); the same arguments extend to micro-transit. Consider the range of emerging services: E-vehicles, bus rapid transit, light rail, various types of scooters and mopeds, microcars, cargo bikes, carsharing, bikesharing, ridehailing services and so on. Each mode has its own technical specifications and could benefit substantially from dedicated infrastructures, ranging from separated lanes and preferential parking places, to grade-separated solutions and supporting energy services. Clearly, however, large-scale provision of infrastructure for all these modes is impossible, if only for lack of space and funds. This does, however, possibly open up new avenues (figuratively and literally) for one of the oldest and arguably the most environmental and efficient¹⁹ vehicles: the bicycle.

¹⁹ Walking is arguably the most environmental and space efficient.

14.5 *(Re)cycling back*



Figure 14.5: Bicycling standing the test of time. Photo by Kevin J. Krizek.

Lastly, we arrive at the third of the Reduce, Reuse, (re)cycle mantra. Cycling is a travel mode enjoying a renaissance of sorts and one that has demonstrated remarkable resilience over time (See Figure 14.5). Cycling's international stock is relatively high in current transport dialogues. It is green, efficient, flexible and comparatively cheap to provide for. Originally a luxury good at the onset of the 20th century, reserved for the elite, its progression flourished hand in hand with the auto industry, before quickly being usurped. Notwithstanding the onslaught of motorists hijacking the 'good roads' promoted by bicyclists, taking the best engineers, and making cycling more hazardous, bicycling has been resolute as a mode of transport for the committed. But is cycling resilient enough to reach the American masses in the coming decades? In other words, is the transport landscape changing enough to allow it to push through the three barriers that have historically suppressed it from flourishing: bad weather, long travel distances, and dealing with exposure to cars?

²⁰ Recognizing also that the weather in the north-central US and much of Canada is worse than most of Northern Europe, which, while further north, is blessed by warming Atlantic currents.

WEATHER. *There's no such thing as bad weather, just bad protection* – this is the mantra of many northern Europe.²⁰ For mere mortals, however, wind, rain, sleet, snow, hail, humidity and heat are problematic for cycling. Warming temperatures owing to climate change are mostly helping, not hurting winter cycling conditions in many cities in the Northern Hemisphere (recognizing, however, that increased precipitation hurts cycling conditions, and warmer temperatures make summer cycling less attractive). Nevertheless, more bicycling requires continued cultural shift of people's tolerances of a commute to work (or travel anywhere, for that matter) in conditions that are less than optimum. If 70 Fahrenheit (21C) (and sunny) is a temperature 'sweet spot' to lure most people into cycling, any fluctuation more than 10 degrees (5C) on either side of it prompts either the 'sweat' or 'freeze' factor. Cities like San Diego, California fare well in this respect, holding a consistent temperature; most other places do not.

²¹ And there is a great deal of potential innovation here, see e.g. the Copenhagen Wheel. (Anneal 2013).

²² (CONEBI 2015).

²³ (Research 2015).

²⁴ (Dave 2010).

RANGE. The upper distance range for those who cycle regularly usually bumps up against three miles (5 km). Technological advances are changing that. New brands of bicycles have roll-cages and weather proofing. But the strongest frontier for cycling lies in amping up its power via batteries. The e-bike has caught on in select markets.²¹ Within Europe alone, 1.1 million were sold in 2014.²² Over 100 million e-bikes are reportedly on the road in China.²³ Considering lifecycle costs (including fuel/energy production, infrastructure, maintenance, manufacturing and operation), e-bikes are estimated to be 12 times more cost-effective than buses, 7.2 times more cost-effective than urban rail systems, and 13.2 times more cost-effective than cars.²⁴ Improvements in battery technology and renewable energy sources can only enhance these numbers.

By reducing levels of effort from humans to better combat the wind, hills, or simply longer distances, new markets of users are quickly emerging (e.g., the elderly, the less physically fit, the commuter with a greater than 3 mile (5 km) commute). The e-bike has the potential replace everyday trips made in cities and metropolitan regions across Europe, even when hilly or windy. Yet, such advantages will only materialize if the latent demand for e-cycling is addressed via infrastructure investments with respect to safety and security.²⁵

²⁵ Better technologies for keeping your bike from being stolen, or making it easier to recover.

SAFETY. Discussions of more cycling revolve around safety. Whether the dangers of cycling in any particular location are real or

perceived is less important; cyclists and fast moving cars fail to mix well. Cyclist comfort matters. First order remedies include:

- Slowing cars (at least on some shared corridors to better share limited space),
- Protecting cyclists via space that is both horizontally and vertically delineated (i.e., curb, plastic bollards), by far the most relied on strategy recently, and
- Removing cars (i.e., prizing completely separated corridors).

While road-repurposing won't really affect prevailing bicycle travel distances or weather, it can dramatically increase the overall amount of space devoted to cycling facilities on many city streets. Meshing the benefits of paint (plasticity) with cycling's flexibility and efficiency implies that the *bicycle is the mode with the most to gain* by subscribing to prescriptions within this chapter.

14.6 *Ending Modal Warfare*

Similar to the competition between cars and transit, there has been a highly vocal and occasionally violent modal war between cars and bikes. (just search for 'War on Cars' or 'War on Bikes').

Standards and technology 'wars' can be brutal. The word war is a metaphor, but not entirely unreasonable. Edison characterized electrocution as 'Westinghousing', to promote his preferred (but doomed) DC transmission system as safer than the shocking AC alternative promoted by Westinghouse and Tesla.

The minicomputer vs. mainframe platform wars took years to resolve, but the personal computer vs. minicomputer wars resolved more quickly. Everyone knows the Mac vs. PC wars have filled many screens of Usenet postings.

All of those however are today meaningless, and one wonders why people were so religious about a technology standard with the rise of mobile computers (smartphones), which most of you possess.

Moving from electrical engineering/computer science to civil engineering, our really old readers will remember the wars between turnpikes and the canals. (Well, okay, remember is probably not the right word, will recall history tell of). Both modes were largely deposed by the new steam train, and neither has many flag-bearers today.

Horsescars were replaced by electric streetcars (trolleys/trams). The streetcars were, with post-bellum nostalgic bitterness,

'bustituted' by buses, but buses, like the streetcars before them, were kicked over to the sidewalk by the automobile.

There was great rivalry between electric, steam, and the internal combustion engine (ICE), but we know how that turned out. Almost all cars today have an ICE with small electric systems with very large batteries driving the starter and the other appliances (radios, lighting, etc.). It's just an everyday case of technological endosymbiosis. This will be revised as EVs rise.

²⁶ (Norton 2011).

There has long been a war on walking, waged (and mostly won) by motordom, as described by Peter Norton in *Fighting Traffic*.²⁶ The US lacks a radical pedestrian advocacy organization (Jaywalkers United ... Will Never be Divided) and some cities want pedestrians to carry 'orange flags of surrender'²⁷ when crossing streets. This war is not just over convenience or user interface preference. Lives are at stake, like in a real war. The war is asymmetric, not too many motorists are killed by pedestrians.

²⁷ (Gottfried 2014).

- Bikes and cars compete for market share (though not much of a competition in most of the US).
- They compete for mindshare, which explains all of the religious advocacy to partisans assuring themselves of their rightness within their bubbles.
- They compete for public funds.
- And, this is where it matters from a transport planning perspective, they compete for roadsapce.

What does the future look like though? As transport gets smarter and follows paths from other technologies, we remove waste from the system.

In short, if we do reduce this waste, as described earlier in the chapter, cars will be the right size for the job, and trips will only be made when they are worthwhile, each trip-maker paying for the cost that trip imposes. We will recognize that road infrastructure has been largely overbuilt. This implies we will generally have ample capacity for both cars (which will be narrower and automated and electric and seat a single passenger and far less a danger than now) and bikes (which may have electric supplements built inside the frame), as well as, on selected corridors, buses (which will have the right number of seats for their passengers). When capacity is scarce, the road owner will allocate capacity based on value using prices.

All of which is to say, the war between cars and bikes probably has a half-life of about 10-15 years as this technological transformation

of the car and roads takes place. This is not to say that fighting the good fight doesn't have some value – bike lanes now are better than a 50% chance of a bike lane 15 years from now, and will save lives in the interim. The faster the systematic switchover takes place, the sooner there will be safe transport everywhere.

14.7 Discussion

Most roads – at least in the US – are too wide. Many are too long as well (e.g., it is possible to reduce the paved rural grid from a 1 mile to a 2 mile spacing in many places). Yet roads generally lack sufficient depth (pavement thickness) to support more economically efficient heavier vehicles without premature failure. Some of the excess width and length should be gracefully abandoned. It may not be worth demolishing, but entropy can have its course. When it is to be rebuilt, it can also be appropriately rescaled. The term 'road diet' is sometimes used, and applies in cases.

But one point is well founded: roads are overbuilt for today with declining per capita travel, and way overbuilt for tomorrow with autonomous cars making more efficient use of capacity. *Travel patterns in the US do not warrant more net road pavement.* That does not mean all communities have all the needed infrastructure. There surely are some investments that have benefits that exceed their costs. It also doesn't mean that all infrastructure should be abandoned. Most infrastructure is quite useful, and developed land is conditioned on the existence of that infrastructure. Thus, wholesale abandonment is not practical. *However for every lane mile added, more than a lane mile should be decommissioned or reused elsewhere.*

It is conceivable that in the future, many cities – particularly American ones – will finally recognize the systematic over-allocation of public space in urban areas to the auto. Most of today's right-of-way is devoted to 6 foot vessels in 12 foot wide corridors. Little is reserved for pedestrians, bicycles, transit, or any variety of yet to emerge types of vehicles, reducing, reusing, and cycling have room to grow.

Speculatively, it might be best to move to a model without pre-defined lanes, where vehicles move as near each other as necessary without colliding, like people walking in crowds.

The interplay of autonomous vehicles and bicycling is also worth considering. New small vehicles: imagine automated electric bikes, enclosed automated electric bikes, Segways with roofs, advanced golf carts, electric Tuk Tuks,²⁸ and the autonomous neighborhood

²⁸ (Autoblog 2015).

electric vehicle, will compete for market share in the niche the bike presently occupies. And they will compete for roadspace on designated bike lanes, with similar operating characteristics and guaranteed safety. Though that local travel niche avoiding the traditional automobile may increase overall, the desire to bike may not fully become mainstream with so many new options on the table.

Figure 14.6: Stationless bike sharing, Shanghai. Photo by David M. Levinson



15

Accelerating the End of Traffic via Pricing



Figure 15.1: Gasoline pumps have been in use since the beginning of the current US transport financing regime in the 1920s. Photo by Pixabay.com (CCo license).

By just traveling around most communities, even a naive transport eye can detect three characteristics endemic in most urban transport systems:

ROADS DETERIORATE. Minnesota, for instance, claims about 6 percent of state roads have poor ride quality and about 3 percent of state bridges are structurally deficient. This says nothing about local roads and bridges though. While you will not pay attention to road quality where the roads are smooth, rough roads, like a five year old, insist upon you noticing them. And roads will only get worse if insufficient revenues are raised to maintain and reconstruct existing infrastructure, as existing roads continue to age and deteriorate. In

short aside from the one-day the newly repaired road opens, roads are worse today than yesterday. There are both mundane reminders – the pothole you hit every morning – and tragic ones like bridges that collapse.

THERE'S MORE TO DAILY TRAVEL THAN JUST GETTING TO WORK. People shop, go to services, visit friends and the sort. Non-work travel has temporal flexibility but most of it happens during peak periods because travel appears free (un(der)priced).

CAR TRAVEL AFFECTS SOCIETY AS A WHOLE. Cars increase crash risk, they creates parking problems of crashes, pollute the air, and exasperate equity issues – all of these are what economists call negative externalities. But these side effects are rarely paid for by the traveler (i.e., drivers don't pay for their full cost).

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In countries with advanced economies that have ubiquitous vehicles and networks, there is a fundamental disconnect between allocation and funding. The link between *who uses what infrastructure at what time* and *who pays for that use* is broken. For the large sums that US society devotes to transport,¹ drivers should expect to savor its splendor. A structural feature at the core of these problems is the lack of an apparent price that is sensitive to time of day, location, and costs. In describing five funding alternatives that quickly move beyond the interest level of the naive eye, we cover the range from the shopworn (though still viable) to the futuristic.

15.1 Gas Tax

In the US roads are partially funded with the under-loved gas tax; general revenues pick up the slack. General revenues are the primary source of roadway funds. This is especially true for local roads, as most localities fail to have a user fee the way states do and instead rely on property taxes. general revenue sources impose costs on non-users as well as users. They also send no signal about the appropriate amount of roads that should be built or how scarce road space should be allocated. There is some relationship between property taxes and roads of course, as access via roads gives property value, but this is extremely loose compared to actual usage of the roadway. Raising gas taxes as a road user fee is more administratively efficient in the short run than implementing tolls owing to lower collection costs.² It is a technically easy way to raise revenue. Simply send the tax collector to each fuel wholesaler once a year and query the number

¹ Limiting to recent US federal legislation (i.e., MAP-21 from 2012) suggests \$40.3 billion for highway and bridge improvements in FY 2013 and \$40.9 billion in FY 2014. Both are slightly more than the \$39.9 billion invested in FY 2012, but less than the \$41.9 billion enacted by Congress for highway improvements in both FY 2010 and FY 2011. Most federal highway investment is used to upgrade and maintain the nation's core highways, including the Interstate Highway System, and to repair and replace deficient bridges. The most ever invested in highway improvements by the federal government was \$68.9 billion in FY 2009. Information from (American Road and Transportation Builders Association (ARTBA) 2010). This excludes state and local funding, which is about twice as much.

² (Levinson and Odlyzko 2008).

of barrels of oil that were sold.

Furthermore, the gas tax serves as an adequate (but not great) environmental tax. Many pollutants are proportional to the amount of gasoline burned. Their economic effect, however, depends on when, where, and how they were burned as well. As a congestion tax, however, it is clearly deficient. It fails to differentiate travel by location or, more importantly, time of day.

While the gas tax is better than the alternative of general revenue, or not paying for roads at all, it doesn't address some important problems. In particular, traffic congestion is a problem. It is not getting measurably worse, but it is not getting obviously better. Even if traffic reduces in the aggregate, it won't disappear to zero in the next decade.

And, it turns out that many transportation systems management strategies are effective at the edge of congestion. For instance ramp metering, the traffic light at the end of the freeway on-ramp that tells you whether you can enter, is most effective by keeping traffic just below the critical point at which congestion sets in (See Appendix for details). If traffic is far below that critical point, there is no danger of significantly higher congestion in letting an additional vehicle on to the roadway. If traffic is well past that point, there is little value in not letting an additional vehicle on, traffic will be stop-and-go in any case. It is just near that critical point where it matters.

It is often noted that if 10 percent of cars were removed during rush hour, there would be little or no delay. This is true in a way. The problem would be the response of traffic. If there were no delay or other penalty, more cars would try to travel at that time, so getting rid of one slice of vehicles will induce another slice of vehicles to travel. Though cars use slightly more fuel in congested conditions than freeflow, that is insufficient to account for the delays being imposed on others.

Still, states in the US can and should raise the gas tax prior to using property taxes or general revenue to pay for roads because the gas tax is directly related to usage. It is something that can (and should) be done immediately. This should be coupled with assurances that the money gets spent on maintaining the valuable parts of the existing system, not building wasteful new facilities. It will have the effect of raising the cost of automobile travel (and lowering other taxes), and thus deterring total travel by a small amount.

Today combined gas tax, vehicle license fees, and existing tolls cover about half the direct costs of roads – and the other half comes from General Revenue – states could, as a first step, double the

³ Like everything this share is disputed and depends on accounting. Federal gas tax revenue on highways typically exceeds federal spending on highways while gas tax revenue from local roads is less than spending on those roads. It should be noted that gas tax revenue is collected from travel on all roads, not just highways. Instead various sources of general revenue (typically property tax) pay for local roads. For one perspective see (Henchman 2014) and by the same author the previous year (excluding license fees) (Henchman 2013).

⁴ On average drivers would be no worse off (and the system could be constructed so that drivers were not worse off at all).

⁵ (Parry et al. 2007).

federal and state gas tax rate (from approximately \$0.50 today to \$1.00/gallon (~\$0.25/liter)) and replace general revenue sources with user fees.³

Furthermore, insurance is also a fixed cost that people don't think about on a per mile basis. Pay-as-you-drive insurance fixes that. Just \$0.60/gallon (~\$0.15/liter) at 20 mpg (11.75 liter/100 km)) on top of the price of gas would go a long way to further reduce travel. This imposes no net additional cost on average; it just changes in the basis of the cost drivers already pay.⁴

Covering other costs, such as paying for the damage that pollution costs (including greenhouse gases) would require an increase of roughly a \$0.50/gallon (~\$0.125/liter) in the gas tax.⁵ This is a much more complicated step in the US. It asks the gas tax to be something more than just a highway user fee whose revenue is fully spent on roads. What goes largely unrecognized is that this money could offset other taxes and be revenue neutral.

15.2 Electrification

The onset of electrification (discussed in Chapter 5) or other alternative fuels prompts discussion of the inevitable: moving away from the gas tax altogether. Outstanding questions are when and whether states and the federal government switch to something better like direct road pricing, or something worse, like funding from general revenue.

At some point, non-petroleum powered vehicles will become a non-negligible share of free-riders on the road network. Electric Vehicles (EVs) do not require less road pavement or cause less congestion than similarly sized internal combustion engine (ICE) vehicles.⁶ The rate of electrification is unclear, but given federal fuel efficiency requirements, it is plausible that a large share of new vehicles will be EVs or EV-ICE hybrids in a 10 year time frame.

The least painful way to address the looming funding shortfall would be to implement mandatory per mile charges for new Electric Vehicles, and hybrids. Establishing such a system on existing cars would be difficult; but EVs are such a small share now, a share which obviously does not pay a gas tax and whose owners have above average incomes that such a charge is an excellent wedge to move towards road pricing. Expanding an existing per mile charge over time, from an initial base of EVs, and later all new cars and trucks, would be much easier than establishing it on all vehicles all at once.

⁶ EVs accelerate faster, so can lead to slightly reduced headways exiting traffic signals.

15.3 Congestion is Unnecessary

The technologies we discussed thus far – particularly vehicle automation – help increase capacity and efficiency. There can be more vehicles on the networks and ride sharing helps increase the efficiency of vehicles on networks. Other trends, particularly the use of information technology as a substitute for travel for shopping and work purposes will reduce the demand for travel.

But nothing can compare to the potential of road pricing to end traffic congestion as we know it.

Since the 1970s, engineers have tried to use information technology to help with surface transport. That is what Intelligent Transportation Systems are all about. But the most important information technology is price. Price is not itself a good, but rather a technology that provides information about the value at which people will exchange one good or service for another.⁷

It would be a shame to see public policy fail to enter the modern era, where prices vary in time and place, to reflect the real costs of travel. Most other goods have prices that vary with demand. When demand is up for gasoline, the prices rise. When supply rises, prices fall. The price matches consumer willingness to pay with supplier willingness to accept. Getting on-board with this concept sooner rather than later can simultaneously solve the problem of funding and allocation, reducing if not eliminating congestion.

When travelers drive an untolled road in the US, they still have a price to pay: their time and the monetary costs of operating an automobile, including gas taxes. But such prices contain little information, and do not represent the costs they impose on the system (their marginal costs). The cost of fuel does not reflect the cost of traveling during the peak (except to the extent that fuel consumption is higher in stop-and-go traffic), or the cost of traveling on costly or critical facilities. The price travelers face is neither real-time nor real-space, but rather an abstracted expectation of some fraction of average costs.

Money can be transferred and store value, time cannot. Thus congestion delay is a loss. If instead of charging time by having travelers waiting in a queue, the road agency charged drivers a congestion toll equivalent to the delay they imposed on others, that loss could be eliminated.

Tolls create revenue. Road owners can take some of that money and use it to operate and maintain existing infrastructure. Tolls may create a surplus. That surplus can be returned to the general public (for instance, through lowering some other tax or providing an

⁷The common term is congestion pricing. Versions have been successfully implemented in cities including London, Stockholm, and Singapore among others. Almost all economists like congestion pricing. For further information, see: (Lindsey 2006).

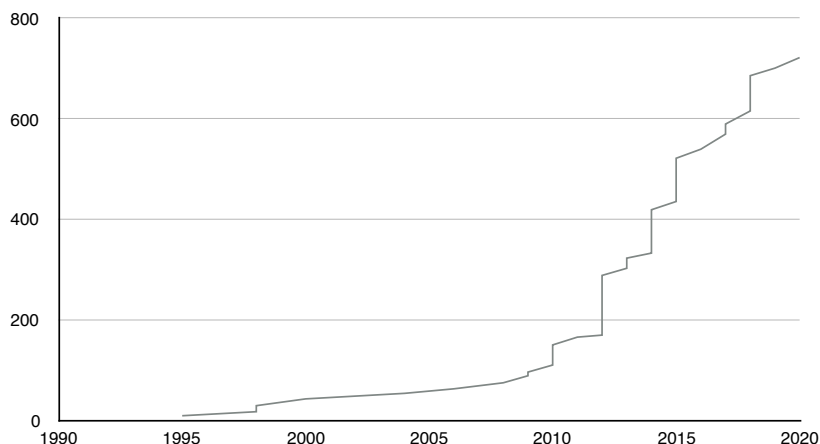
annual road dividend – make the rebate as progressive as you like, it doesn't matter from a transport perspective). Surprising as it may seem, society as a whole would be better off.

This requires political will and public acceptance for people to exchange money for time. To date, the public is skeptical when they are unfamiliar with road pricing, but supportive after seeing it in action. Returning congestion pricing revenue back to the neighborhoods where it was generated may help.⁸ Phasing pricing in one Electric Vehicle at a time seems an obvious strategy.

⁸ (King et al. 2007).

15.4 Networks of HOT Lanes

Figure 15.2: Cumulative length high/occupancy toll lanes in United States. Sources various. Special thanks to David Ungemah and Mark Burris.



The onset of High Occupancy/Toll (HOT) or express lanes is already happening across the US (Figure 15.2). Whereas road pricing requires everyone to pay for use of the facility, HOT lanes allow users to opt into paying a toll in exchange for assurance of uncongested travel (or travel for free or a discount if they are in a carpool). In the near term, we foresee HOT lane networks running adjacent to most urban freeways in the US, shaving some time off for those who chose to pay. HOT Lanes are compatible with road pricing systems that do not entirely eliminate congestion, as they provide higher reliability (just as FedEx offers alternative rates for same-day, overnight, and two-day delivery).⁹

⁹ The end result might be parallel HOT lane networks and conventionally priced networks that have some crowding, but off-peak discounts.

HOT Lanes will also be important because they are likely to be the first roads to be entirely automated. Given their isolation from other lanes and the premium price, they can be automated much sooner than other roads, which will continue to serve mixed human and automated traffic for at least another decade past the onset of select

lanes for automated cars.

15.5 *Reservation Pricing*

Roads are first-come, first-serve. They have been generally designed to allow aspiring car drivers the freedom to do so by showing up and getting on the road. Sometimes this requires queueing at a ramp meter to wait for the opportunity.

On some freeways High Occupancy/Toll (HOT) lanes guarantee free-flow travel times, but have tolls which vary dynamically. In the case of dynamic tolls they are intended to ensure the toll is high enough to prevent congestion.¹⁰ However with the dynamic toll, travelers don't know the toll until they are already on the freeway, about to decide between using the priced lane or not. Almost everywhere else, the price on a road is guaranteed (\$0) with variable travel time.

The driver faces either uncertainty on price with certainty on time, or certainty on price and uncertainty on time. Ideally, there should be an option to have certainty about both of these.

First-come, first-serve is not the only way to allocate space. Nice restaurants don't allocate table space that way during prime time. Parking structures do not. Theaters do not. Airlines do not. Private race tracks do not. Public roads need not.

At its most primitive level, for instance, every day the commuter pre-purchases a ticket (electronically, on a smartphone app or over the web, or via an in-vehicle communication system) to use a particular road segment (for instance between exit 400 and exit 401) during a particular time slot (say between 7:45 and 8:00). The ticket cost is known in advance before departure, like a plane ticket. The road agency would only sell as many tickets as the road would accommodate (without congestion) at that period. The ticket would be validated electronically through some form of Electronic Toll Collection.

Roads are unlike airports with spacious waiting areas. Travelers might arrive with their vessels at 7:44 or 8:01; but the road agency does not force the car onto the shoulders. More likely, the agency could charge a penalty which increases with deviation from the purchased window. So if the charge were \$2, there might be a \$0.10/minute surcharge added for each minute early or late the traveler was.

If the system were deployed universally, congestion would be a rarer occurrence.¹¹ Furthermore, the system would know whether the traveler or the agency was the cause of the earliness or lateness.

¹⁰ The MnPass system in Minnesota, among others, is a good example of such.

¹¹ Non-recurring congestion would still be an issue, owing to crashes and other incidents, but not the daily recurring congestion because of excess demand for the available capacity.

If there were non-recurring congestion, the agency might waive the penalty. In contrast, if the traveler left too early or too late to reasonably make their slot under planned for circumstances, the surcharge would stand.

But travelers don't want to map out their route every day. To simplify, the agency could just sell a ticket allowing travelers to be 'on the roads' (as opposed to being on a specific road), and let individual travelers sort out the best path. The losses from not micro-managing prices spatially are relatively small, compared to the gains from spreading traffic out by time of day. Traffic information providers like Waze, TomTom, and others will help advise travelers, or their autonomous vehicles directly, what routes to take.

For instance, the traveler pre-purchases a ticket to use any metropolitan area road between 7:00 and 7:30 am. The total number of passes is limited by system capacity. If the purchase is made far enough in advance the price is lower than if the ticket were purchased just-in-time. But few people want to plan their schedule that far in advance, or log-in daily spending even 5 minutes to buy tickets for a 20 minute trip.

Here the road agency managing the system can be a little bit more clever. They could sell various types of season passes (just like transit agencies). A traveler might buy an unlimited use pass for a premium, but there would be a limited number sold to residents in each zone. Or they could buy a more limited use pass at a lower price. And of course, travelers would buy these as recurring subscriptions, billed to a credit or debit card account. Like utilities, most people would just pay their bill, but some travelers will respond to incentives at the margins.

People without passes could take their chances with same-day tickets which might be more expensive when traffic is on the edge of congestion, or cheap if traffic is low that day. Once properly set up, these passes replace existing revenue sources for the agency.

How should the road allocate these passes? Clearly it should not just give them away. But setting a fixed price and selling them does not allow discovery of demand patterns. Here auctions might be appropriate. For instance, the passes would be available at a posted price ('buy-it-now'), but the agency would also accept lower bids. Suppose there were 100 passes, there would be a bidding period, and at the end of the period, the top 100 bids would win and the price would be set at the willingness to pay of the 100th bidder. There are many variations on auctions (what we described is referred to as a Dutch Auction).

Each have different advantages for buyers or sellers in terms of maximizing revenue or price discovery or fairness. Certainly there are trade-offs between efficiency and equity, and some users will be priced off the roads – if they weren't, what would be the point? There will also be some uncertainty if passes are auctioned, especially as price discovery takes place. The degree to which this is a problem or a feature remains to be seen. We believe it can all be made to work, as other market goods do. Concerns about equity can be ameliorated by giving funds or vouchers to people with low income.

15.6 Separating Roads and State

Road pricing for financing and congestion management in the US remains under the guise of existing institutions doing the pricing. To date, this has essentially been a non-starter. With institutional reforms, reconfiguring state and local DOTs as public utilities rather than departments of government, the logic the public applies to roads will change, from one of a public service paid by the pot of general revenue to a fee-for-service proposition paid for by direct user charges.

Many traditional utilities share with transport systems the characteristic of having a networked structure. Most, if not all, of these utilities are operated on the basis of payment-for-use. Utility pricing varies regionally. Some locales vary prices by time of day, and users often have the option of choosing different rate plans. Utilities can manage demand by altering infrastructure, repackaging services, substituting technologies, and changing the price of service.

Transport agencies have considered all of these, but implemented them weakly. In reverse order: Prices are largely invariant, technological (modal substitutions) are not viable for most passenger or freight users, bundling and packaging of services is not considered when looking at pricing, and infrastructure is hidebound to engineering standards, and difficult to modify. One could easily imagine more creativity on the part of road providers in all of these aspects. The constraints on the application of creativity are due to the engineering culture in a public agency, where risk-taking is discouraged if not punished, and certainly never rewarded.

Australia and New Zealand demonstrate that it is possible to transfer the utility model of governance to road transport. This model separates the organization delivering the service from the client, is subject to rate regulation, and implements a more direct,

user-pays system of financing. While planning and scope of service decision will remain political, the utility model could depoliticize *management* of the existing transport system. One expects from experience with other utilities, toll roads, and road concessions in other countries that it would be politically necessary to have some public guarantee of an upper bound on the rates a road utility could charge, as provided by a regulatory agency. The risk is that an upper bound on revenue would be too tight, resulting in financial losses, as occurred in the private mass transit sector throughout in the US in the early to mid 1900s. Still, public utilities have a “mean level of trust” of 42%¹², which is much higher than the trust in the federal government, hovering in the 20% range in good, peaceful years.¹³ Interestingly, private utilities may provide better environmental outcomes, as they are easier to regulate than public agencies.¹⁴

¹² (Jenkins-Smith and Herron 2004).

¹³ (Pew Research Center for the People and the Press 2010).

¹⁴ (Koninsky and Teodoro 2014).

Taxes or charges of any variety are unpopular; but there is an issue of framing with any poll, and a general problem of the public not believing that user fees are dedicated to transport, even when the law says they are. Instead people, most of whom don’t think about transport finance much, assume that gas taxes go to general revenue – which is true in many countries, but not in most states or the federal government.¹⁵ While marketing and education campaigns would help, there are fundamental issues of trust. This is an institutional problem, which can be rectified by separation of roads from the executive branch into a public utility.

¹⁵ “Raising the gas tax is unpopular among voters as well. A poll from the Eagleton Institute at Rutgers University found that two-thirds of New Jersey residents oppose an increased gas tax. The poll noted, however, that opposition fades when people learn the taxes would pay for repairs to crumbling roads and bridges.” (Gould 2014).

15.7 Implementation

THE MOST WIDELY DISCUSSED PRICING SYSTEM IN THE US IS A MILEAGE TAX CONCEPT, sometimes employing GPS systems.¹⁶ There are a variety of potential technologies for assessing mileage taxes, most use GPS (or an equivalent such as cellphone triangulation) to identify location, since one of the advantages of these types of systems is the ability to charge different rates for different locations (city vs. country, freeway vs. local street, congested vs. uncongested road).

GPS receivers do not normally transmit information but GPS-equipped vehicles can log the vehicle location. Some additional communication technology, which might report a reduced form of information (e.g. total amount owed) would be used to complete the transaction. For instance, a pilot study in Oregon had a chip in the vehicle log distance traveled by geographic zone and time of

¹⁶ (Forkenbrock 2008).



Figure 15.3: Oregon road pricing trials are branded OReGO.

day, without storing the precise location.¹⁷ The chip only reported the total charge owed, calculated by an onboard algorithm. So no detailed tracking information was shared. Simpler technologies such as a mileage based user fee would simply record the odometer reading, but this would not allow differentiation by time of day or location. For individuals concerned about privacy, they can pay peak prices all the time. We suspect most people will choose to reveal information about time and location to save money (by getting off-peak rates). Oregon is presently testing a voluntary mileage charge (1.5 cents per mile) for up to 5000 participants dubbed “OReGO.”¹⁸

¹⁷ (Zhang et al. 2009).

While road user charging remains an attractive prospect, its application may still be many years away due to a combination of privacy concerns, implementation and transaction cost issues, and technological development issues.¹⁹ Some of these concerns might be obviated under a different governance structure, where it was neither the legislative nor executive branch of government making these decisions.

¹⁸ (Rose 2015).

We argue here that congestion exists, governments should price roads to encourage use in the off-peak and discourage use in the peak. The revenue obtained should first and foremost be used to operate and maintain existing roads. Furthermore, it should largely replace existing funding sources (fuel taxes, vehicle taxes, property taxes). Surpluses should then be returned to taxpayers.

¹⁹ (Levinson and Odlyzko 2008).

Prices need to be systematic, not just on specific routes, to maximize system efficiency. Random sets of underutilized toll roads

fail to advance this aim because 'free' roads remain congested. Pollution and noise and crash risk all need their own externality charges. This will collectively reduce the vast waste in existing system, and turn roads into a highly efficient freely flowing system, with cars incentivized to carry multiple passengers, and travelers motivated to travel when it is less congested.

Changing how roads (and transit) are governed could do this. A logical first step is to implement pricing on vehicles that do not now pay the full gas tax. Continuing to roll out HOT Lane Networks will accelerate the adoption of automated vehicles, by providing a network that can be transitioned rapidly into an all-automated network where vehicles will find a more predictable environment with capacity and throughput increased significantly.

Redeeming Transportation



Figure 16.1: The future of transport depends on what happens in developing countries, and whether they repeat the mistakes of before, or learn. This more optimistic scenario is from Wuhan, China. Photo by David M. Levinson.

The first and second editions of this work were titled *The End of Traffic and the Future of Transport*. Vehicle travel in most fully industrialized countries is falling, slowing or stagnant.¹ Per-capita vehicle travel in the US is roughly where it was in the late 1990s. And, vehicle miles traveled, the number of miles that cars move, is roughly where it was in the mid 2000s. The significant change is that these trends follow 90 years of steady, almost uniform increases in the amount of automobile traffic. Barring a few exceptions owing to economic downturns or energy shocks, vehicle miles traveled increased almost every year in almost every setting for an entire century!

¹ Quarterly figures from the US Department of Transportation reveal how the US has seen per capita vehicle travel well off the peak for more than an entire decade (total vehicle travel has plateaued too, but not as severely owing to population gains). See: ([Office of Highway Policy Information and Travel Monitoring 2014](#)).

THE AUTOMOBILE REGIME, IN ITS CURRENT FORM, IS DEMONSTRATING CONSIDERABLE SIGNS OF INSTABILITY.

There are complementary hypotheses as to why people are driving less per capita in 2015 than 2000. When we ask “What Killed America’s Traffic?,” we identified some of the important ones, which include the price of fuel, the declining workforce, changing driver license regulations, telework, online shopping, and virtual connectivity with friends.

These last three reasons for traveling less by car (and overall) are due to information and communications technologies (ICT) substituting for travel. They are not mainstream transport explanations. Varying demographic sectors use ICT in different amounts. Just as your parents or grandparents once did, and may still, receive a physical issue of the newspaper while you read online, your children are more likely to be early adopters of future technologies than an older you, your parents, and grandparents. And the habits formed while young likely persist over time.

One could easily argue, therefore, that the future in cities is less about traffic per se. It might even be less about traditional transport as a whole – the primary rationale for why we titled the 3rd edition of this book, *The End of Traffic and the Future of Access*.

THE TRANSPORT SECTOR’S LIMITED ROLE. Within the transport sector alone, there have been small policy shifts over the past 15 years. But these don’t really help in explaining the decline of travel.

Increased use of walking and bicycling play a role and work well for short trips; they certainly have niches they can grow into if land development intensifies and people reorganize their lives to enable them. When David lived in Minneapolis, he was one of the 7% of Minneapolitans who walked to work. The numbers, while rising, are much lower outside core cities, and nationally (3%).² Kevin often rides one bike from his ever changing fleet of bicycles in Boulder. While these types of activities are increasing, nationally, they explain maybe 15% of all travel (work and non-work). And while transit ridership is up, it is up ever so slightly.

There are a slew of ‘new mobility options’ which use information technologies to allow travel without owning an automobile, but are not yet visible in the broader transport statistics. These include peer-to-peer taxi and ridehailing services, dynamic real-time rental cars, and the like. While these are useful in their niches, they are not yet cost-effective to be the main transport mode for the vast majority of the population. Today they are supplements when the main mode doesn’t solve ‘the job to be done.’³

² According to (US Census Bureau 2017).

³ The ‘jobs to be done’ framework is due to Clay Christensen, a Harvard Business School Professor. (Clayton Christensen Institute 2017).

EMERGING TECHNOLOGIES. Technologies allow people to do more of the same, and they allow people to do new things. It is easier to predict more of the same than new things. Now couple the emerging changes in transport technologies with the trend of decreasing car use that is evident in the US and other countries in the developed world,⁴ and we argue Western societies on the verge of a transformative technological revolution in the transport sector, akin to how information technologies have restructured many other economic sectors.

⁴ Future demands for cars at peak travel, see: (Ministry for Transport 2014).

AFTER SIX DECADES OF QUIESCENCE IN THE AUTOMOTIVE SECTOR, VEHICLE AUTOMATION IS COMING. Self-parking cars are already here, self-driving cars are in test-mode on real streets in mixed traffic, and the auto industry predicts mainstream use on roadways by 2020. Big changes are close enough in our horizon that we can not only see it, we can smell it. Admittedly one cannot smell tailpipe emissions on electric vehicles, but we still hope they have that new car smell. Soon enough we will taste these changes, metaphorically.

ROADWAY EFFICIENCY. In contrast to the magical two-second rule that was ingrained in driver's education classes,⁵ driverless cars, when unfettered by pesky humans in the mix, will follow at startlingly small intervals.⁶ Slender autonomous cars will travel in narrower lanes.⁷ The process of decommissioning the last human-driven car will be a long evolutionary one, but probably will not happen prior to 2040. Before that though, HOT Lane Networks will be converted to automated-only operation. Prohibitions of human-driven vehicles from some, many, and most roads at some, many, and most times will occur gradually over the next several decades, as networks are converted to the new technology, just as horses became increasingly uncommon.

⁵ It was taught that you should follow the car ahead of you with at least a two-second gap – a value that is often disregarded at rush hour and hovers nearer 1.8 seconds.

⁶ California's Drivers Handbook in fact recommends a "3 second rule," which is apparently not hard-wired into the minds of California's actual drivers. (Department of Motor Vehicles 2017) (p. 34).

⁷ Platoons of connected vehicles, have been tested with 1 meter following at highway speeds of 60 mph (100 km/hr). A world with all driverless vehicles will likely double linear capacity. There is horizontal space savings on top of that. Two passenger smaller cars might travel space of 8 ft rather than 12 (bringing an additional 50% increase in capacity). Even more slender one passenger cars might travel in a space of a lane of 4-6 feet instead of 12 feet (100% increase in capacity).

DAILY TRAVEL. Taken to an extreme, these conditions suggest a future where travel – a daily 1 - 2 hour set of chores of getting to things and having things come to us – might be a thing of the past. Driving to work five days a week and driving to the big box store for detergent are both disappearing. The Amazon Dash button demonstrates how we might address some such chores. And, parents will soon be able to order a self-driving car to take their children to soccer practice. Relying on descendants of apps like Skype and FaceTime, workers will meet colleagues periodically at both offices and random third places. Yet-to-crystallize effects will be rendered by 3-D printers.

STIMULUS EFFECTS. While the traditional workplace will shrink in size and importance, it will not vanish. Work, like shopping and much of life, has a social as well as economic function. Furthermore, like all social and information networks, bytes also have stimulus effects. Possible substitution effects inevitably need to be addressed on a global stage. While metropolitan travel might drop, absent war or economic collapse – both quite real possibilities – international travel will continue to rise for decades. The consequences of that on the environment depend on progress in the aviation sector, particularly the use of biofuels.

DEMISE OF TRADITIONAL MODAL WARFARE. New vehicles portend the end of modal warfare as is currently conceived. Cambrian explosions of new and attractive combinations of modal travel will mitigate the car versus bus and car versus bike strife – strife that has riddled discussions (and therefore, progress), for decades. Transit and cycling advocates continue to lambast car-oriented planning and policy priorities. The antagonism between the two draws from a great struggle that has been playing out in the twentieth century between *Mass Motorization and Mass Transit*.⁸ It is a conflict that continues to this day and has spawned a morality play in the culture wars. While transit and cars mostly serve different markets, at the margins they compete for users, roadspace, funding, and the hearts and minds of travelers. They are competing on old turf though.

⁸ (Jones 2008).

While limited resource issues still suggest a zero-sum game, new modes and new fusions of existing modes will change the calculus. Cities will increasingly struggle to find ways to reconcile competing demands of existing modes – and new ones – within limited street space.

The good news is that transit advocates, fortunately, can now stop trying to put the (transit) genie back in the bottle because the bottle itself has now changed radically. Given the demise of modal warfare, more reliable transport services will form around the passenger rather than the facility or vehicle. On the other hand, the battles between the new modes could be quite significant, as we see with Uber's largely illegal invasion of cities and the varying public sector responses, from acquiescence to arresting drivers.

IN 'THE MORE OF THE SAME' CATEGORY, EXTRAPOLATION OF HISTORICAL TRENDS GIVES MORE TRAVEL. Generally as the cost of travel declines, travel increases.

VALUE OF TIME. Automation changes the value of time. Today's cars require active driving with hands on the wheel and eyes looking forward, periodically checking the rear-view mirrors. Like transit today, tomorrow's cars allow the passenger to pursue other activities. What this means is you may be less concerned with a few extra minutes in motion, since you are able to do something more pleasurable than watching traffic (though as Transport Planners and Engineers, we have a hard time seeing what that could possibly be). If you read or watch or type or listen or talk or shave or apply make-up or eat or drink (far too much of which happens now while driving), you can do so without concerning yourself about exactly what your car and its neighbors are doing. You would still prefer not to be in motion, but not by nearly as much as today.

MOBILITY-AS-A-SERVICE (MAAS). Autonomous cars make the so-called new mobility options most useful in cities; they may be more useful in less dense suburbs than transit is today. Instead of owning a car, renting on demand is more viable. The right-sized car can in principle be summoned at any time. Instead of paying a fixed cost of ownership once (independent of use), and a variable cost that includes only fuel and time, imagine an alternative world where the cost of car use pays for the fixed cost of ownership on a per trip basis. If a driver is paying by the minute when the car is used, instead of paying for a car loan or lease by the month, the incentive structure the driver faces changes. This would significantly raise the out-of-pocket costs, thereby discouraging driving. It also makes driving better and less frustrating as there will be fewer cars on the road. It might also lower the total cost of transport, since individuals would no longer have so much capital tied up in vehicles, and would drive more efficient cars, less often. This is independent of, and multiplicative with, any reductions in vehicle use that could arise with increased ride-sharing enabled by logging your planned trips in advance. This counters the historical trends, and argues travel will be less frequent and more thoughtful. The daily pattern of transit for routine trips and MaaS for special trips becomes feasible.⁹

LAND USE EFFECTS. We identified two possible land use effects. Increasingly, driverless cars will make it easier to drive by reducing the cognitive burden on the driver. An initial effect, assuming people continue to own their cars, is the 'out' scenario. People would travel farther, to places they are less familiar with, and move to places farther from their place of work. They would thus be able to get more real estate for the dollar. Today's commuter rail

⁹ The lack of effective MaaS options now pushes people to owning vehicles, and once they own a vehicle, they are going to use it. This new lifestyle model works in cities, where transit can be a mainstay transportation mode, and MaaS are conveniently located. It works less well in the suburbs, exurbs, and rural areas, where the baseline transportation mode cannot be as expensive on a per-trip basis as the MaaS rental model requires, but the density is not high enough to support fixed route transit on most corridors.

passengers travel farther (and longer) than auto users, and autonomous vehicles, where the passenger can do something else while traveling are more like commuter rails than are today's cars. Such cars can deposit drivers in front of buildings and park themselves, reducing the amount of time that drivers spend parking and accessing and egressing their cars, which would naturally lead to longer distances. Autonomous vehicles are likely to be safe at higher speeds, since humans won't be driving, which will also lead to longer distances in the same travel time. They expand mobility for those who are now restricted (the young, the disabled, and so on). But electrification will likely affect perceptions of accessibility and land use effects.¹⁰

The other scenario – 'up' – depends on the success of Mobility-as-a-Service within cities, and will lead to urban intensification as city-dwellers shed their cars and obtain mobility on demand from MaaS providers and micro-and macro-transit systems.

VEHICLE FLEETS. Obtaining more efficient use of existing capital out of the surface transport fleet through MaaS will reduce the lifespan of cars by using fewer vehicles more intensively, and wearing them out sooner. Airlines are already onto this model, keeping planes in motion as much as possible. Thus MaaS vehicles will on average be newer than today's fleet. As technology continues to advance with greater rapidity, this becomes increasingly important. The difference between a 2030 and 2020 model car likely will be far greater than the difference seen between any decade since 1920 and 1910.

PERCEPTIONS OF CITIES. Hybrid-electric and electric vehicles will be more common, if not the only vehicles allowed on city streets, eventually. The smell and sound of the city will change; it might even have that new car smell. Cities with more EVs will be less polluted and nicer, and thus more attractive than cities smelling of diesel and petroleum, or horse poop that populated the streets decades prior. There will be lower levels of tailpipe emissions, even for transit vehicles and trucks. There will be less confusion about the degree to which cities are better for the global environment. There is already emerging evidence that they produce less overall carbon emissions than lower density areas with greater distances and fewer shared walls. But they might soon be as good (if not better) for the individuals residing in them, with less overall pollution per capita and perhaps lower pollution intake than suburban areas. (The suburbs will fight back with solar power though).

¹⁰ Today our internal combustion engines give us a range of maybe 500 km. Battery powered vehicles currently give many potential travelers 'range anxiety.' While not yet in the DSM, (The Diagnostic and Statistical Manual of Mental Disorders, a catalog assembled by the American Psychiatric Association of the many ways the mind goes wrong), 'range anxiety' is the fear that your electric vehicle will not be able to get you where you want to go throughout the day within the range of the existing battery. As Chapter 5 describes, many of yesterday's and today's battery powered cars have had limited ranges (on the order of 120 miles (200 km)), which is beyond most people's daily travel, but not everyone's, and not every single day. So the issue of recharging or battery swapping is relevant, and may add to travel costs. Just as recharging the phone is a daily issue for smart phone users, and filling the tank is weekly for most people with cars, daily or sub-daily charging might be important. If autonomous, this may be able to be done when there are no passengers in the car, so from the passengers perspective, there is nothing to notice. But for long trips, this may present a limit on the practicality of electric auto-mobility.

Outside of cities, there will be less change. Mobility-as-a-Service proves less practical the farther one is from other people, since dispatching the car takes time. Longer distances means speeds will be higher. Thus, the privately owned automobile will remain important for rural, small town, and suburban markets that cannot justify the fixed cost of high capacity transit services nor have a thick enough market to enable vehicles on-demand within a timeframe customers will accept. However, that auto or light truck will be automated, and will eventually be electric as well.

“There is an urgent need to move beyond the techno-determinism that surrounds discussions about innovation in transportation, that have become bogged down in a Silicon Valley versus City Hall narrative, the innovate upstart versus the hidebound local regulator.” – Anthony Townsend¹¹

¹¹ (Townsend 2014).

In previous chapters we described what has happened, or more speculatively, what might happen. The future of transport has always had more unknowns than knowns. Its overall character depends on many moving parts, and primary among them is how quickly forms of innovation take root and the changing density of land use activities. Key aspects of the future will happen on their own, following a technological trajectory more-or-less independent of policy intervention; other dimensions can or will be accelerated by policy intervention.

By 2050 an estimated two thirds of the global population will live in cities (10 percent of the world’s population will live in ‘mega-cities,’ larger than 10 million).¹² Urban personal transport will be more multi-modal. The appropriate mode, as always will depend on the trip. But technology will change which modes are appropriate for which trips. We imagine different scenarios in different places.

¹² (The Economist Data Team 2014) predicts 8.6% of world’s population will live in Mega-cities of 10 million or more by 2030, growing at about 1% of the world’s population per decade.

For the shortest trips, within and between buildings, on campuses, and in neighborhoods, walking will remain dominant.¹³ Escalators and elevators will remain as alternatives to staircases, but moving sidewalks are likely to be rare, limited to special environments like airports. Standard bicycles have stood the test of time for a century; being relatively cheap and environmentally efficient, their overall stock may rise for trips in the 1-5 km range; newer and modified forms of electric bikes will rival more traditional forms of transport for longer distances.

¹³ We do not foresee Segways or Pogo Sticks supplanting feet in most places.

But the bulk of urban personal transport vehicles using ‘everyday streets’ will likely be comprised of small ultra-light, smart, battery-based vehicles that would be hired (not privately owned), both MaaS transport for the fully customized point-to-point trip and micro-transit for less cost, semi-customized shared rides. Cars

that drive themselves change how people use such devices.

These combinations will most profoundly affect medium distance trips, possibly feeding traffic to fixed route systems. Mixing vehicles of different sizes and desired speeds will always remain a challenge; mixing with automation raises the stakes. Though in many ways this is transitional. Humans will eventually be fully removed from the driving loop, when additional controls can ensure different types of vehicles mix safely.

These smaller battery powered vehicles – along with walking and cycling (electric bikes or other) – would seamlessly integrate with macro-transit: large scale, fixed route, high-capacity public transport systems. Higher volume mass transport will remain important, particularly in existing and emerging high density markets. Today's largest cities support busways and rail transit, and those will remain in markets with heavy demand. Between cities, rail, intercity bus, and airplanes will continue to provide travel options.

Inside dense cities and even major suburban corridors where the geometry is favorable, the driverless bus will compete with the driverless car on price, assuming pricing is fairly representative of service cost. MaaS transport finds a middle ground here. Flexibility is aided by designing networks and land use patterns that can be served by transit as well as MaaS transport, rather than one that is served exclusively by autonomous vehicles.

Modal options will function, if not seamlessly, with fewer seams than today. Payment and access would be nearly instantaneous via smart phones, watches, or biometrics. The overall system will more closely integrate the digital with physical transport. Software will intelligently work out solutions in real-time. It will be safer as evidenced by fewer and less severe crashes. Yet, as the system is tuned more toward efficiency and away from hyper-safety, it is likely to be perceived as more frightening (for motorists and non-motorist users alike).

In contrast, the suburban, exurban, small town, and rural transportation landscape will look more familiar, with private, but now autonomous cars, shuttling people about. Traffic lights will be slowly dimmed. There may be less shuttling as going to work and going shopping diminish in frequency, but these are slow, almost imperceptible changes, until one-day we wake up, and realize the world is different from how it once was.

Cumulatively, *auto-mobility will be redeemed* from the many externalities it causes today (death, pollution, noise). Cars will continue to take more space and require more energy than efficient

transit, but will increasingly beat poorly conceived transit services. These are gradual processes. The rapid change in information technology can inform the direction of changes in transport, but the pace cannot be replicated. The lifespan of a private car (15-20 years) far exceeds that of a smart phone (about 3 years). The technology that people possess lags far behind the technology that is possible. Information and transport technologies differ in fundamental ways. Building roads or rails have socio-spatial implications that laying fiber optic cables or constructing cell phone towers do not.

With the emergence of peak travel and autonomous vehicles just over the horizon, society needs to think not about adding road capacity but maintaining what we have and what we need. As with railroads from the 1920s through the present, rationalization of the network – strategic reductions or right-sizing – should take priority. Such a conversation is not occurring.

The mountain analogy implies society cannot climb to the peak of the next technology in the same market niche (for instance, serving daily transport needs) until it climbs at least partway down the first. One can imagine a technological helicopter or zip line, or leaping off the peak (deprecating or abandoning existing functional technology, rather than just depreciating it over time) to accelerate transformation, but such sudden changes are rarely wise and even less politically acceptable, with entrenched interests having accumulated power desirous of maintaining (or expanding) the status quo.

If the future of transport does *not* involve more information technology and more automation, *we will be both surprised and disappointed*. Its exact shape and character is hard to pin down but will be rapidly evolving.

In the 1980s, there was a vision of a future of telecommunications and information that was something like what the Internet came to be, all the world's information at your fingertips. But few foresaw that it would be supported by online advertising. The idea that a collaboratively-built online encyclopedia would displace Britannica, and be among the world's biggest websites, or that an online bookstore (a bookstore!) would become the world's largest online retailer were all unpredicted and unpredictable. So it is with transport in the early 21st Century.

A

Now Extinct: The Traditional Transport Engineer

THE *traditional* TRANSPORT ENGINEER, WHO DESIGNS ROADS, HIGHWAYS, AND INTERSECTIONS, AND TIMES TRAFFIC LIGHTS, SHOULD VIEW HIS FIELD AS ON A LONG SLOW DECLINE, much like the railway engineer (not the train driver) of a century ago, or the irrigation engineer once people discovered water runs downhill. A century ago, railway engineers understood how to design and run a railway far better than people today, because that is what they focused on, and that is the sector that, almost two centuries ago, attracted the best and brightest minds of their generation. This doesn't mean there won't be any traditional transport engineers, just many fewer in the developed countries. Agencies can of course use the released staff time to design in more detail, to higher quality, and so on. Or agencies can redirect the efforts of new engineers to address the resulting problems, to sectors that are continuing to grow, to new opportunities, to different transport problems. Future transport engineers can think about how to better use scarce road space in cities to serve people rather than vehicles. The profession can move beyond the mindless application of arbitrary level of service standards that have beset our communities.

In contrast, new professions will emerge. For instance, *traffic programmers* will write algorithms control cars interactions with each other.

Today we talk about traffic engineering, designing infrastructure, timing traffic signals, identifying where signs and markings go, and so on to improve the efficiency of moving cars (and ideally people) through the system (where the network itself is a given). This is distinct from transport planning, which identifies where infrastructure should go and what policies should be in place. This

also differs from highway engineering, which looks at the geometric design of facilities, ensuring the horizontal and vertical curvature are safe (for human drivers at a given speed). There are other related professions as well: urban designer, bridge engineer, pavement engineer, and so on.

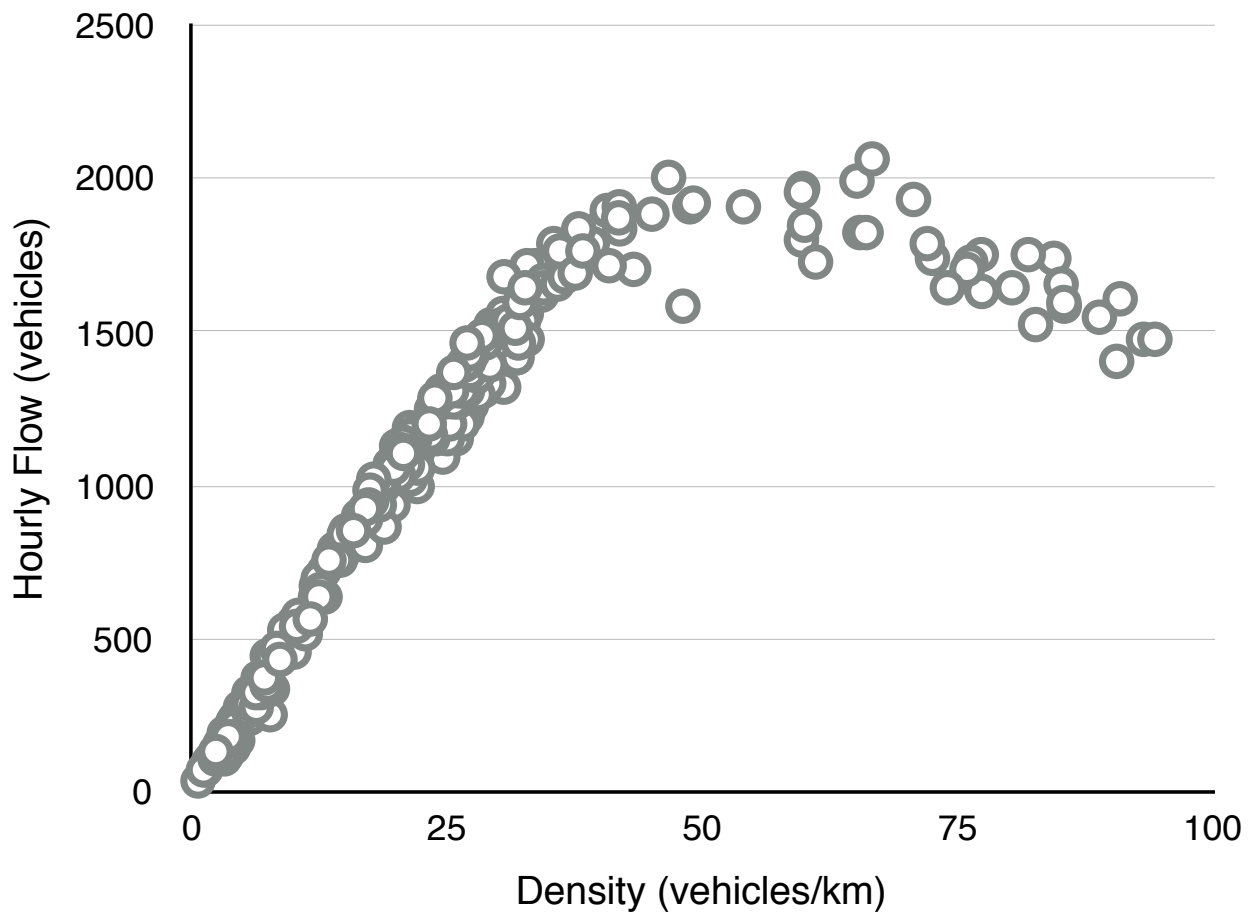
Traffic programming will not be *simply* (or *not simply*) modeling human traffic, or re-arranging infrastructure, but instead will be designing algorithms to control vehicles in real-time. This field grows out of computer science, electrical engineering, industrial and systems engineering, and mechanical engineering, but will need to fully consider the environment around the vehicle and how to react to it. The early stages of this already exists, there are engineers and programmers designing autonomous vehicles. But they are doing so in a way that is autonomous -- recognizing the existence of neighboring objects, people, and vehicles, but only optimizing for itself.

The traffic programmer of the future will design vehicles to do that but also communicate with neighboring vehicles, and coordinate with the system at a routing level as well. Effective connected vehicles will come after effective autonomous vehicles.

With appropriate price signals, we can do things now like aligning the system optimal interests of the network as a whole with the user optimal desires of the individual (autonomous or not) vehicle. Whether pricing can work to provide the right incentives on the give-and-take of traffic merging and lane changing is less clear. Drivers today negotiate that through eye contact and the actions behind the wheels. Finding protocols to do this automatically, and to negotiate directly between cars in real-time will be the task of the *traffic programmer*.

B

Traffic, What Is It?



If we are foretelling the end of traffic, we should define what we mean. Figure D.1 is an illustration of what traffic engineers call the Fundamental Diagram.

Figure B.1: Flow vs. density.
Source: MnDOT All Detector Report, Detector 1942 (I-394 near US 169), 2000-11-08, 5-minute counts, ramp meters off.

Flow (q) is the number of people or vehicles past a point per unit time (usually expressed as vehicles per hour or persons per hour).

Capacity is the maximum flow that can pass a point per unit time. The capacity depends on the road, the vehicle, and the driver. If we were all race car drivers, at the same spacing between vehicles, we could get a lot more vehicles past a point. Alternatively, if we drove a lot closer together at the same speed, we could also increase throughput. However there are reasons we don't do this. We have to consider human reaction times.

When taking driver's education, you may have learned the two-second rule, in good weather follow the driver ahead of you with at least a two-second headway. If everyone did this, we could get 1800 vehicles per hour per lane past a point.

Recall there are 3600 seconds in an hour, dividing by a 2 seconds per vehicle gives 1800 vehicles per hour. In fact, limited access freeways in good weather during peak periods have a much higher throughput, sometimes observed as high as 2600 vehicles per hour per lane, though more typically between 2000 and 2200, indicating people are ignoring the two-second rule, and are following more closely.

The reason for the 2 second rule is that if the driver ahead of you slams on the brakes, you have some amount of mental processing, referred to by engineers as 'Perception-Reaction Time', to see the brake-lights, have your brain tell your foot to move from the accelerator to the brakes, and push hard yourself.

Density of traffic (k) is the measure of the vehicles per length of roadway.¹ When you are the only car on the road, the density of traffic is low. When there are lots of cars on the road, the density is high. The density of traffic indicates the Level of Service, which is a grade that traffic engineers apply to roads, and ranges from A to F. Just like your report card, from the driver's point-of-view A is better than F.

The maximum density, called 'jam density,' occurs when vehicles will line up end to end, and none can move until the car in front moves. If cars were on average 5 meters long, and literally 'bumper-to-bumper,' there could be 200 cars per kilometer per lane. In practice cars are longer, and they are only figuratively bumper-to-bumper, so jam density is nearer 125 cars per km per lane (200 cars per mile per lane). But as the saying goes, 'Your Mileage May Vary,' and this result depends on many factors. At jam density, traffic does not flow.

The relationship between traffic flow, density, and speed (v) (how fast those vehicles are going, i.e. distance per hour) measured at a

¹ The letter k is used because it comes from the German word 'konzentration.'

point, typically a bottleneck location can be expressed as an equation:

$$q = kv \quad (\text{B.1})$$

where: q = flow, k = density, and v = speed.

So why does the 'Fundamental Diagram' have the shape it does (Figure D.1)?

When density on the highway is zero, the flow is also zero because there are no vehicles on the highway. As density increases, flow must increase if speed is constant. It turns out, that we can drive the speed we want to, unaffected by other drivers, at lower traffic densities. So if there were only 1 car per kilometer, you travel at what is called 'freeflow speed,' and if there are 2 cars per kilometer, or 5 cars per kilometer, you are still largely unaffected by the other cars. However as density rises, you are eventually slowed by other vehicles.

There is a maximum throughput (capacity), determined by the minimum following headway. In good conditions, drivers can travel at freeflow speed up to that point, but then congestion sets in, and as more cars are added, everyone slows down due to queueing. At jam density, flow is also zero.

Queueing is a technical term (that is, it is a British term) for standing in line. Imagine a road has a capacity of 1800 vehicles per hour (1 vehicle every 2 seconds). Imagine further that 2000 vehicles arrive in a given hour (and then, no more vehicles arrive). How many vehicles are left after 1 hour? (Answer: 200).

The line is 200 vehicle long. In this case, it will take another 400 seconds (200 vehicles times 2 seconds per vehicle), or 6 minutes and 40 seconds to discharge the queue. The last vehicle in the queue arrived at the end of 1 hour, and waited 6 minutes and 40 seconds. The first vehicle arrived at the beginning of the hour and did not wait. The average wait for vehicles during that hour was 3 minutes and 20 seconds. (This is also the wait for the vehicle that arrived at the half-hour point).

The bottleneck still serves a maximum of 1800 vehicles an hour. All 2000 vehicles eventually get served. There is however delay, and the delay is manifested on the road as traffic in a slowly moving queue of 200 vehicles at its peak.

Ideally the queue is slowly moving. In practice there are many stops and starts because humans are driving, and humans are imperfectly attentive (if not perfectly inattentive), and will either not drive at a constant velocity, or will brake too sharply when the car in front brakes, or not brake at all and cause a crash, or so on. Further

Any transport facility will have the properties of speed, flow, and

density. However the maximum speed, the maximum flow, or the maximum density may change with the technology being used.

So when we say there will be an 'end of traffic,' we mean it not in a literal way that there will be no cars, which collectively comprise traffic (just as datum is the singular of data, car is the singular of traffic). Rather we mean it more colloquially, that the presence of other cars will either diminish (there will be less traffic) and that the effect of other cars will diminish (because capacity will be higher). Our perception of traffic will decline. It will cease to be a problem.

C

Forecasting

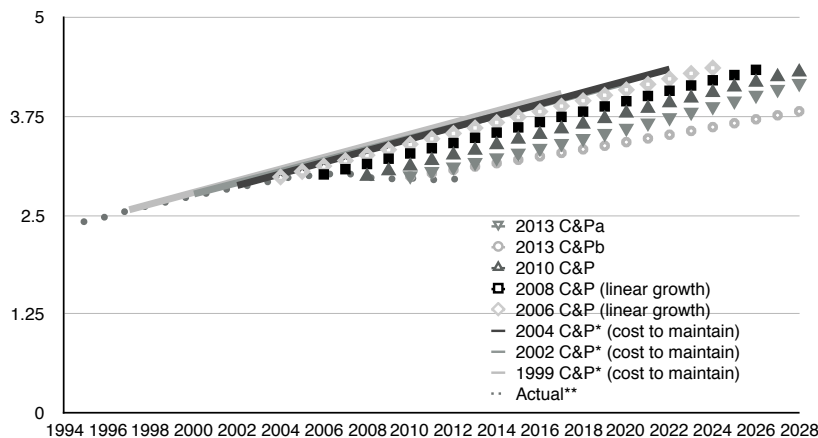


Figure C.1: US DOT highway travel demand estimates (Trillions of Vehicle Miles Traveled) continue to overshoot reality. Source: (Sundquist 2014) (Used with permission).

Combined traffic projections from state and regional transport agencies (the colored lines) have been wildly off the mark (the black line shows real traffic levels) for more than a decade.

When David was a naive young modeler, developing the Travel/2 regional travel demand model for the Montgomery County Planning Department, such models took up to 24 hours to run in full form. Talking with modelers today, it seems models still take on the order of 24 hours to run. Why?

We posit "Induced Complexity." When we build a road, we induce demand, travelers who were previously priced off the road due to congestion or extra travel time now switch times of day, routes, modes, and destinations to take advantage of the capacity, and new development is pursued. Similarly, when we get a bigger computer, we can either use it to run the same models faster, or to run more complicated models. It seems the profession leans to the latter. The complexity is in terms of the number of Transport

Analysis Zones, or in the number of times slices in a day, or in the number of model components that are considered, or the degree of precision required in equilibrium.

This induced complexity is real, and like induced demand is not necessarily a bad thing (if the complexity improves accuracy, it is a good thing), but it is a thing we should all be cognizant of.

¹ (Parthasarathi and Levinson 2010).

Yet, forecasting of this nature is notoriously bad.¹ Figure C.1 shows the error in the aggregate.

There are many reasons for this, but one is structural, failure to understand the life-cycle dynamics. The reason for overshoot and undershoot can be understood by visiting the S-curve. Assumed forecasts are made by extrapolating previous results, which is how many businesses and investors and government agencies operate, as shown in Figure C.2. In early years (Birthing and Early Growth) the rate of growth each year is greater than the previous year. Someone extrapolating from history will undershoot actual growth. But in late growth and maturity, growth is slower than the previous year. Someone extrapolating from history will overshoot actual growth.

Extrapolation models are common in transport. These are used for statewide modeling in many places. Such forecasting methods (assume growth continues at a fixed percent) is embedded in some textbooks, especially for instance, in pavement design.

Urban transport planning models are better in some ways, in that they include multiple factors. Unfortunately, these models are based on rates at a single point in time. Thus they assume the mathematical function that describes traveler's behavior is fixed, only exogenous (input) factors such as demographics, land use, networks, and policies are allowed to vary. Even when multiple years of data are available, such models are typically only estimated on the most recent survey, rather than on trends or changes. The underlying behavior is not permitted to change, only what it responds to. Yet we now have evidence that some underlying preferences do change over time. It is not simply a matter of getting the demographics or incomes correct. For instance from the 1960s to the 1990s female labor force participation increased. Thus the number of work trips and non-work trips (substituting out-of-home for in-home production) both increased in that period. But that increase has played itself out. Thus the increases it was associated with have peaked. This reflected changing preferences. While hindsight is 20/20, we don't know if underlying preferences can be modeled accurately prospectively (we are doubtful), but we do know failure to account for them will lead to model inaccuracies.

What changes are going on now that are not considered in travel

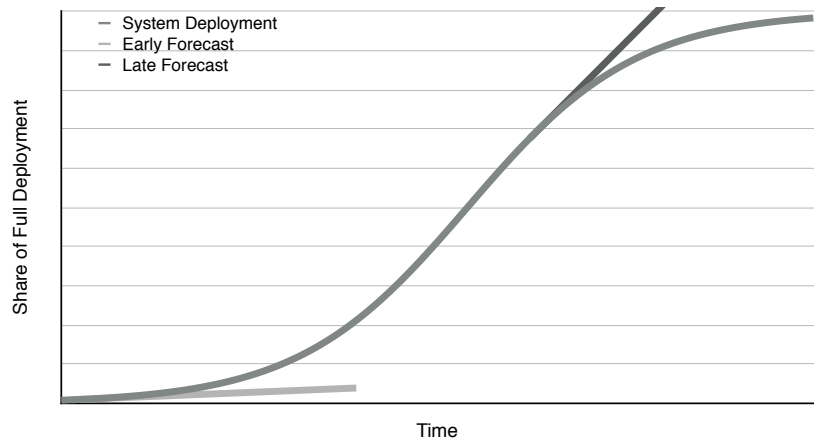
demand forecasting? A brief (and very incomplete) list below:

- Vehicle technology shifts (driverless vehicles)
- Preference shifts (and economic scarcity) among young travelers
- Changing driver licensing requirements
- Vehicle ownership vs on-demand vehicle rental (car "sharing")
- Telecommunication increasing substitution for work, shop, and social travel
- Telecommunication complementarity for work, shop, and social travel

None of this is easy to model, certainly not within the existing framework of urban transport planning models, even more modern activity-based models. In many ways it is easier to do macroscopic than microscopic forecasting. The question is, if some kinds of forecasting are impossible (we can forecast traffic pretty accurately two weeks from today, but not the first Tuesday of 2044), why do we do it? Is there a human-need to fill the void of future uncertainty with authoritative assertions?

Speculating about the future is useful, it opens up pathways. Developing scenarios is useful, it challenges assumptions. Thinking about the lifecycle process and markets helps frame the possible, the plausible, and the likely. Studying history (and past forecasting methods and errors) provides humility and insight. Visions (and alternative competing visions) help establish what we want. Developing a communal hallucination can organize individual activities to become the ideal (or nightmarish) self-fulfilling or self-negating forecast. Planning needs more methods for thinking about the future than single point forecasting.

Figure C.2: System deployment vs. extrapolative forecasts. S-Curve and the Danger of Extrapolation Source: Figure 29.2 from (Garrison and Levinson 2014).



D

Access, What Is It?

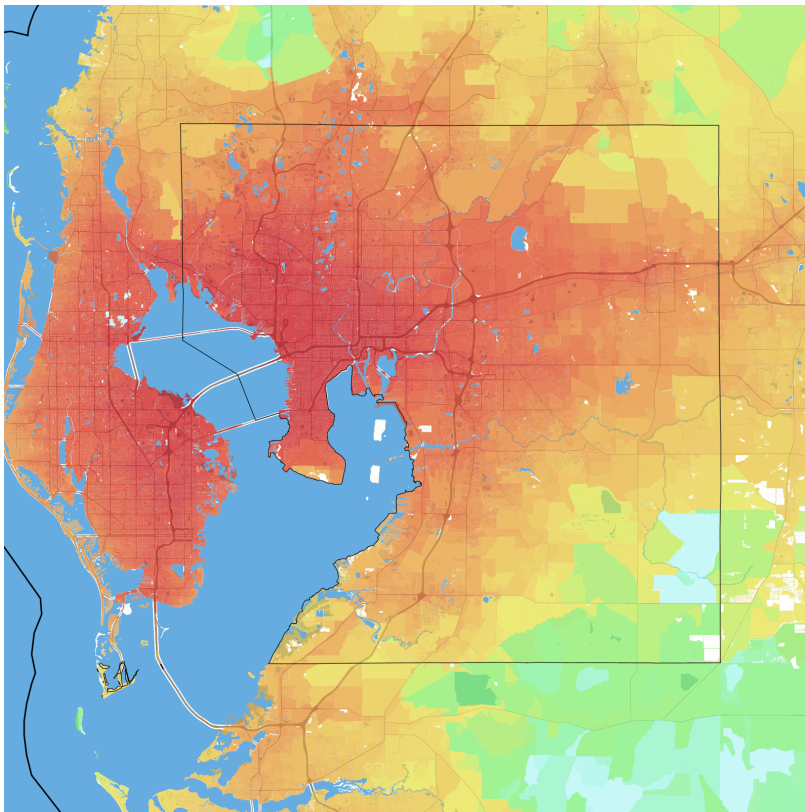


Figure D.1: Figure D.1 An Accessibility Heat Map of Tampa Bay region. Red indicates higher accessibility. Source: Accessibility Observatory.

Access – the north star of transport analyses – typically has measured the ease of reaching things (e.g., number of jobs which can be reached within 30 minutes travel time by car at 7:00 am on a typical weekday). One can change the travel time, the mode, the time-of-day, or the destination and develop another measure. The travel time could be converted to a monetary cost (or monetary costs could be added to the time) to account for tolls, or paid

¹David led an organization called the Accessibility Observatory, which measures these things across the US, and Kevin has worked on similar projects).

parking, or transit fares and the like. These variants work reasonably well for today's world.¹ For tomorrow's world, not so much.

For instance, typical accessibility measures look at the shortest travel time path. The shortest travel time path by car assumes you store a vehicle where you live (on your property) and park it at your destination (on its property). With autonomous vehicles picking you (and only you) up, the start and end points might be the same for you. If you share a ride, there will be deviations adding to your travel time (but presumably reducing your out-of-pocket cost). But because these are dynamic, there will be variation from day-to-day that is greater than today's variation due to traffic or transit schedules. If you walk to a car rental (as today's car2go operates) (rather than being picked up taxi-like) that adds an additional access cost. Paying per trip also adds an out-of-pocket cost that today is mostly ignored. Or it might be a combination of time and money. Instead of how many places can you reach in 30 minutes, how many places you can reach in \$10 out-of-pocket costs by mode might be the relevant factor.

E

(Why) Is Transport Underfunded?

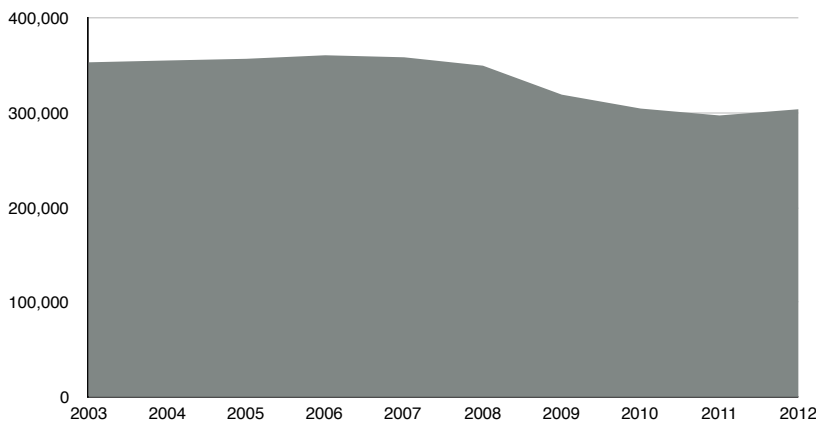


Figure E.1: Highway, street, and bridge construction employment. Source: (US Bureau of Labor Statistics 2014b).

Many professionals in the transport community consider surface transport to be underfunded – there are unmet ‘needs.’ National reports from industry groups urge more resources. Local reports are similar. ‘Needs’ is one of those words with which economists have difficulty; in transport circles it has come to mean things for which the benefits outweigh the costs (subject to the usual debates about what are the benefits and costs of any given project).

The claim that the US is spending too little on transport has several arguments in its favor.

- On the side of ‘too little’ are some economists, following on the heels of David Aschauer’s¹ work about the infrastructure investment shortfall. They claim, based on selected macro-economic analysis, that infrastructure investments drive economic growth.
- There are arguments about economies of agglomeration,² which infrastructure may enhance, operating through

¹ (Aschauer 1989).

² (Melo et al. 2017).

accessibility. To the extent accessibility increases, agglomeration increases too. This is likely to be non-linear, but may be increasing or decreasing in a particular range.

- There is also the stimulus argument, from macro-economists looking for useful jobs projects, to employ the unemployed.
- Having some redundancy in the network is also valuable, as it makes the network more robust to failures (such as terrorist acts, bridge collapses, or superstorms).
- Stronger roads and bridges would enable buses and trucks to make more efficient use of labor by carrying more weight.

Certainly the quality of services could always be improved, pavement repaired, bridges strengthened, bus stops made more useful, buses modernized, etc. Money enables any of these things and therefore, the solution often comes back to finding more money. Yet the sector has been steadily getting less rather than more money (in real terms and as share of GDP) at the federal level and in most states. So if costs are low, and there are clearly needs, why can't it close the gap?

THE SATURATION HYPOTHESIS. The industry is saturated. One concern is that maybe the amount of resources to do the work is limited, so we can't physically get more infrastructure built. If there were a limited number of contractors, and they were all fully employed, more money would simply mean higher prices and a reshuffling of priorities not new building.

There are steep barriers to entry. It is difficult to start a road construction company and get contracts from the regional provider. Assuming firms are fully employed now, all they would do is demand higher rates, defer something else, to do the new thing.

Contractors claim they are not fully deployed, and certainly could add some employees and acquire additional materials. How high is capacity utilization in the road construction? How close to fully employed is the sector? Figure E.1 shows that from a 2006 peak, the sector was once 20 percent larger in employment. Clearly a lot of this is due to the effects of the recession on local government spending, but recovery is very, very weak. Evidence is the road-building sector is far from fully utilized, there is a lot of slack to handle more road building. More expenditures in road building should not significantly drive up prices at this time.

It is hard to conclude that even 2006 was "full utilization," there is always elasticity (if wages are high enough, some people will put off retirement, others will be attracted to work in the sector). Some

equipment can be transferred from building other types of projects to road construction. New equipment can be ordered, equipment and labor can be moved from other states. The real world is not black and white, but as capacity utilization increases, prices increase faster than output. However in the absence of full utilization, prices should be relatively cheap. If firms don't need to go to extra effort to hire workers and machinery, (i.e. they would otherwise be idle or working at marginal tasks), prices will be stable.

The analogy here is a bottleneck. At well below capacity, travelers can proceed at free flow speed. Only as capacity approaches does delay (higher prices) result.

THE CYNICISM HYPOTHESIS. While there are needs, money won't go to needs. Political rent-seeking will divert funds from what matters. Cynical as this may be, there is some evidence for this. The construction industry itself is indifferent to what is built, so will happily support any spending. It is the users and taxpayers who suffer from the misallocation of resources, not only in the opportunity cost of what isn't done, but the future maintenance burden of supporting what was done. Spending money may solve today's macro-economic unemployment problem (though the stimulative effects of road building in the modern capital intensive era are weak), but spending it poorly creates future problems. We have no evidence that giving more money will result in it being spent on the things the public cares about.

INFRASTRUCTURE IS GOOD ENOUGH HYPOTHESIS. People don't perceive the same needs as industry does. Most roads and bridges are in good enough shape. Most people drive on those good-enough roads. The perception is limited to what people actually travel on. As Charles Lane says: "So how come my family and I traveled thousands of miles on both the east and west coasts last summer without actually seeing any crumbling roads or airports?" Even Lane acknowledges "The United States probably needs more infrastructure spending. It also needs a serious debate about how much cash to invest and how to invest it. Alarmism promotes the former, not the latter."

INFRASTRUCTURE IS GREAT HYPOTHESIS. The industry is wrong. There is in fact no need. Not only do we not need new roads, the existing roads are fine too. There is already enough money flowing through the system to keep it in a state of good-enough repair. So what if a bridge collapses every few years, that is nothing compared

to other social problems, like the 35,000 people killed each year in car crashes. Conditions are getting better.

While existing roads are in fine condition, they are congested, so we need more new and wider roads. The purported need for maintenance is just a distraction put forth by the greens to avoid new construction.

PEOPLE ARE SELFISH HYPOTHESIS. People see the problem but don't care about the social outcomes. They would rather have the large screen TV than pay for the better road. Surveys about the acceptability of gas taxes repeatedly find their unpopularity.

THE ROAD-HATER HYPOTHESIS. There is a need, but some people (how many?) don't like roads. They believe there are too many roads as it is. Deterioration is a form of traffic calming, so encourage it.

THE FUTURIST HYPOTHESIS. There may have once been a need, but as we adopt autonomous vehicles, our efficiency (utilization of pavement) will increase, so we will soon need fewer lanes. Since infrastructure lasts a long time, we can get a head-start on the future reduction by not building any more now. While by this point in the book, if you are still with us, you might believe this to be true, it is highly unlikely this is the reason roads are not actually being funded.

If society spent more money on roads, what would it be spent on? The claim that more money won't actually go to needs has merit. There is also a perception bias problem. There is only a problem if you see it every day. Lots of roads are in good enough condition, and bridges don't fall down with alarming frequency. However it is clear anyone who thinks we should be proud of the condition of our infrastructure did not travel on the streets in a northern town.

Whether our communities have too much or too little infrastructure depends on how the infrastructure is distributed and organized. There is not simply a "lump of roads," but rather roads of particular designs, connecting particular origins and destinations, with a length, width, and depth. While the previous section presented the arguments the industry has put forth on why there are not enough roads, this section instead makes the argument we have too many.

We cannot (choose not to) afford to maintain the infrastructure we have. Also worth noting is the lack of economic development impacts³ of most new investments. Learning from history, if demand has peaked, supply is probably also at the peak of what we can economically support. This was true of rail in the 1920s, at

³ (Iacono and Levinson 2013).

which point the mileage of rail networks (both intercity and urban) declined. This may now be true of roads, with peak travel occurring, as we see rural areas continuing to depopulate, some places considering gravelization,⁴ some urban freeways being taken down and not replaced.⁵

It is clear we under-price what we have, so naturally that leads to more consumption than if we properly priced things. It is also clear the roads sector (and some other transport sectors) are in the mature phase of development, and roads have at best diminishing returns on investment, if not zero or negative returns. It is also clear that most roads are mostly empty most of the time, and that we build many roads far wider than are needed, so wide they can be used to store cars 24 hours a day.

We would conclude, that in general, we do have too much road infrastructure.

In the absence of a policy change, the edifice complex, infrastructure infatuation edition, will continue to suck away considerable funds that could be better spent on other things.

⁴ (Albert Lea Tribune Editorial Board 2011; Batheja 2013; Louwagie 2011).

⁵ (Reconnecting America 2013).

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In most industrialized countries, car travel per person has peaked and the automobile regime is showing considering signs of instability. As cities across the globe venture to find the best ways to allow people to get around amidst technological and other changes, many forces are taking hold — all of which suggest a new transport landscape. Our roadmap describes why this landscape is taking shape and prescribes policies informed by contextual awareness, clear thinking, and flexibility.

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A Roadmap to the New
Transport Landscape



David M. Levinson ♦ Kevin J. Krizek